

**Methods of mixing large numbers of heterologous genes.**

All patent and non-patent references cited in the application, or in the present application, are also hereby incorporated by reference in their entirety.

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**Field of invention**

The present invention relates to methods of mixing large numbers of heterologous genes, which are located on artificial chromosomes. The methods of the present invention are useful for evolution of cells and whole genomes to acquire new functionality(ies), such as the ability to synthesise novel secondary metabolites and/or the evolution of novel metabolic pathways.

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**Background of invention**

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Recombination of cells in order to optimise or produce heterologous proteins is a well-established practice in molecular biology.

The traditional approach to engineered molecular evolution relates to optimisation of an individual gene having a specific phenotype. The strategy is to clone a gene, identify a function for the gene and an assay for selecting the gene, mutate selected positions in the gene and select variants of the gene for improvement in the known function of the gene. A variant having a desired function may then be expressed in a suitable host cell.

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However, the traditional approach has several drawbacks when it comes to evolution of cells having new properties, since the approach only relates to discrete genes. Multiple genes that cooperatively confer a single phenotype cannot be optimised in this manner. Furthermore, the traditional approach only leads to a very limited number of combinations or permutations in a cell or even for a single gene.

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Evolution of cells having new properties have been described in for example WO 98/31837 wherein a method of evolving cells towards acquisition of new properties employing iterative cycles of recombination and selection/screening for evolution is discussed.

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In WO 97/35966 a process of recursive sequence recombination in order to evolve new metabolic pathways are discussed, and in WO 00/04190 a process of recursive sequence recombination in order to evolve whole cells and organisms having  
5 desired properties.

Whether using the traditional approach of optimising individual genes or conducting iterative cycles of recombination, the individual genes in the cells in question are recombined, i.e. changed with foreign genetic material evolving new genes.

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A major drawback when evolving new genes in this manner is, that each cycle of recombination may as well result in a failure leading to a nonsense gene as a success leading to an optimised gene. Furthermore, these methods are not very useful for evolution of novel metabolic pathways, since very few gene combination  
15 are produced.

WO 96/34112 discloses a combinatorial gene expression library with a pool of expression constructs each construct containing a cDNA or genomic DNA fragment from a plurality of donor organisms with the purpose of generating new metabolic  
20 pathways. The publication also discloses a combinatorial gene expression library in which each cell comprises a concatemer of cDNA fragments being operably associated with regulatory regions to drive expression of the genes encoded by the concatenated cDNA in a host organism. Once the gene cassettes have been cloned into the vector, it is not possible to excise the cassettes or the complete concatemer  
25 from the vector using a restriction enzyme. The reference is silent on the possibility of changing and optimising the combination of genes in each cell.

Consequently there is a need for developing methods for generation and optimisation of novel metabolic pathways

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### **Summary of invention**

A first aspect of the invention relates to a method of mixing heterologous genes in expression cassettes located on artificial chromosomes, said method comprising the  
35 steps of:

providing two initial populations of cells that can mate with each other,  
said initial populations comprising at least 2 cells in each population, and at least  
two cells in each population having different combinations of heterologous genes  
and/or different combinations of expression cassettes,  
5 each cell comprising at least a first type of artificial chromosome, the at least first  
type of artificial chromosome comprising both at least two expression cassettes  
comprising heterologous genes and at least one selectable marker,  
the selectable markers being allocated to artificial chromosomes so that each type  
of artificial chromosome from each population can be individually selected for,  
10 mating the cells with each other, and  
selecting mated cells that carry at least a subset of the selectable markers present  
on the artificial chromosomes in the two initial populations.

By "a type of artificial chromosome" is meant a group of artificial chromosomes  
15 sharing the same selectable markers. According to the present invention such a  
group of artificial chromosomes comprise artificial chromosomes with different  
expression cassettes or with different combinations of expression cassettes.  
Methods for generation of such artificial chromosomes and the differences between  
artificial chromosomes within the same type are disclosed in the detailed description  
20 part of the invention.

The method provides a possibility for changing the combination of genes located on  
artificial chromosomes in a cell by using simple means as mating and subsequent  
meiosis. Thus the methods of the present invention provides solutions to the  
25 problem of obtaining further mixing of genes that have already been mixed as they  
were selected for insertion into the two initial populations.

Hence, the method adapts simple mating techniques and makes them suitable for  
complex crossings. Because the content of individual cells of a library is not known,  
30 crossing cells of a library is more complex than crossing cells of a specific clone. For  
example, selection of cells comprising artificial chromosomes must be performed in  
order to preserve many different combinations of heterologous genes/gene  
cassettes.

The presence of the artificial chromosomes in the mated cells is ensured by the use of selectable markers located on all the artificial chromosomes. that select for mated cells After mating any sub-set of types of artificial chromosomes that select for mated cells can be used. One example of this is selecting for marker combinations present on at least one type of artificial chromosome present in each of the initial populations.

However in order to conserve the majority of genes while keeping the number of selective media/conditions reasonably low, the subset of the selectable markers selected for should include selection for at least 70 % of all diploid types present in the mated population. More preferably the subset of the selectable markers selected for should include selection for at least 80 % of all diploid types present in the mated population, such as at least 90%, for example at least 95%, such as at least 99%, for example 100%.

The process may be continued by allowing the mated cells to subsequently undergo meiosis. Preferably meiosis is performed under conditions where cells without artificial chromosomes and cells that have not undergone meiosis do not survive. Standard protocols are available to do this e.g. for yeast cells.

Once cells have undergone meiosis and until the next mating round, the cells are kept under conditions where cells without artificial chromosomes do not survive. As the mixing method results in the generation of novel gene combinations it may advantageously be combined with screening of mated cells for a parameter related to a desired functionality(ies) and selecting cells having a predefined selection criterion(a) to undergo meiosis and mating. By screening cells at the diploid level, more genes are present in each cell, and consequently the chance of generating novel metabolic pathways is higher than at the haploid level.

Screening may alternatively comprise screening cells that have undergone meiosis for a parameter related to a desired functionality(ies) and selecting cells having a predefined selection criterion(a) to undergo mating and meiosis.

The mixing, mating, selection and preferably also further meiosis steps may be repeated to stepwise optimise the gene combinations or evolve novel gene



combinations by repeating the process at least twice, such as 3 times, for example 4 times, such as 5 times, for example 6 times, such as 7 times, for example 8 times, such as 9 times, for example 10 times, such as 11 times, for example 12 times, such as 13 times, for example 14 times, such as 15 times, for example 16 times, such as 17 times, for example 18 times, such as 19 times, for example 20 times, such as 25 times, for example at least 30 times, such as at least 40 times, for example at least 50 times, such as at least 75 times, for example at least 100 times, such as at least 200 times, for example at least 300 times, such as at least 500 times, for example at least 1000 times.

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In order to reduce the accumulation of mutations in the host cells the method may further comprise subjecting the populations of cells to physical isolation of artificial chromosomes from the populations for every 4-5 rounds of meiosis and selection, and transferring the isolated artificial chromosomes into new host cells. The physical isolation may e.g. comprise amplification of artificial chromosomes in the host cells so that the artificial chromosomes constitute up to 20% of total DNA in the cells. Alternatively the physical isolation may comprise cutting expression cassettes from concatamers of expression cassettes on artificial chromosomes, cloning and amplification of these and re-assembling expression cassettes into an artificial chromosome vector backbone and transforming these into new host cells.

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After meiosis, cells of the mating types may be separated from each other.

When working with a spore forming host species, the method may comprise mixing spores from different populations prior to mating. The two populations can then be mixed very efficiently before mating and thus there will be less mating within each population.

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As there is no guarantee that the mixing method according to the invention results in improved genotypes compared to the initial populations or to early rounds of mixing and selection, the method preferably comprises storing a sub-population of mated and selected cells, while another sub-population undergoes further meiosis and mating. According to this embodiment, the method preferably additionally comprises screening of at least a stored sub-population together with a population that has undergone at least one further round of meiosis and mating at a higher selection

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threshold than the previous screening, selecting cells above the higher selection threshold, and mating the selected cells with each other. The method may also comprise screening together with the stored sub-population and/or a population that has undergone at least one further round of meiosis, mating and screening, cells  
5 that contain expression cassettes or combinations of cassettes that have not been screened before.

It is also possible to add a further population of cells with artificial chromosomes comprising at least two expression cassettes with heterologous genes, the cells  
10 being capable of mating with the cells that have undergone mating and meiosis, the further population comprising at least 2 cells with combinations of expression cassettes different from the combinations in the cells of the initial population, the artificial chromosomes of said further population carrying at least one selectable marker. Preferably the artificial chromosomes of said further population have the  
15 same markers as the initial populations. The further population may comprise a 50/50 mixture of cells of the two mating types of the initial populations or it may comprise cells of one of the mating types of the initial populations.

At least one of the two initial populations of cells that can mate with each other may further carry at least a second type of artificial chromosome with expression  
20 cassettes comprising heterologous genes, the first and second types of artificial chromosome carrying at least one selectable marker so that said first and second types of artificial chromosome can be individually selected for. More preferably, at least one of the two initial populations of cells that can mate with each other further  
25 carries at least a third type of artificial chromosome with expression cassettes comprising heterologous genes, the first, second, and third types of artificial chromosome carrying at least one selectable marker so that said first, second, and third type of artificial chromosome can be individually selected for. More preferably  
30 at least one of the two initial populations of cells that can mate with each other further carries at least a fourth type of artificial chromosome with expression cassettes comprising heterologous genes, the first, second, third, and fourth type of artificial chromosome carrying at least one selectable marker so that said first, second, third, and fourth type of artificial chromosome can be individually selected  
for.

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More generally speaking the two initial populations of cells that can mate with each other may carry from 1 to 10 types of artificial chromosomes, each artificial chromosome of each population carrying at least one selectable marker so that each of the types of artificial chromosomes from each of the two populations can be individually selected for.

Similarly, the further population of cells with artificial chromosomes capable of mating with the cells that have undergone mating and meiosis may carry from 1 to 10 types of artificial chromosomes, each type of artificial chromosome of said further population carrying at least one selectable marker so that each of the types of artificial chromosomes can be individually selected for.

According to one embodiment, each cell may carry 2 artificial chromosomes per cell that can mate. According to another embodiment each cell may carry 3 artificial chromosomes per cell that can mate. The number of artificial chromosomes per cell is today considered a practical number, at least in the case where yeast is the host species. This is because this number of artificial chromosomes can be efficiently transferred into and be stably maintained at least in yeast and also because too high a number of artificial chromosomes may cause centromere toxicity, at least when all the centromeres of the artificial chromosomes are identical. It is expected that within the term of the present patent, methods will be developed for stable maintenance of a higher number of artificial chromosomes in yeast and possibly also in other species.

Preferably each artificial chromosome carries at least two selectable markers, the selectable markers being allocated to types of artificial chromosomes so that each type of artificial chromosome from each population can be individually selected for. In this case, one marker is normally located on each arm of the artificial chromosomes to ensure that the artificial chromosomes do not lose any of the arms. Preferably, all artificial chromosomes carry a common marker so that it is possible at any point to select for cells that contain at least one artificial chromosome. Suitable selectable markers are selected from drug resistance, colour, morphology, resistance against electromagnetic radiation, salt tolerance, oxidative stress resistance, markers based on fluorescence probes, and auxotrophy markers, markers that can be used to produce high copy numbers (e.g. a poorly expressed

LEU2 gene (leu-2d), heterologous thymidine kinase (TK), heterologous dihydrofolate reductase gene), heterologous genes that give a growth advantage. More preferably the markers are auxotrophy markers. "Oxidative stress resistance" is meant to encompass resistance or tolerance to reactive oxygen species, i.e. free oxygen radicals.

Specific examples of these markers include but are not limited to: NPT<sup>II</sup>, LEU 2, TRP 1, HIS 3, LYS 2, URA 3, ADE 2, Amyloglucosidase,  $\beta$ -lactamase, CUP 1, G418<sup>R</sup>, TUN<sup>R</sup>, KILk1, C230, SMR1, SFA, Hygromycin<sup>R</sup>, methotrexate<sup>R</sup>, chloramphenicol<sup>R</sup>, Diuron<sup>R</sup>, Zeocin<sup>R</sup>, Canavanine<sup>R</sup>, ARG 4, THR4, Luciferase, GUS, GFP, LUX.

It is preferred that said at least 2 cells of each population comprise at least 2, more preferably at least 5, even more preferably at least 10, yet more preferably at least 20, for example at least 50, such as at least 100, for example at least 200, such as in the range of 10 to 1000, for example in the range of 40 to 700, such as in the range of 60 to 300 expression cassettes comprising different heterologous genes.

When possible, it is preferred that the two initial populations are of different mating types. The size of the initial populations may either be selected so that the two initial populations have approximately the same number of cells. Alternatively, the number of cells in one population is higher than the number of cells in the other population.

In a further aspect the invention relates to a method of mixing heterologous genes in expression cassettes located on artificial chromosomes, said method comprising the steps of

providing two initial populations of protoplasts or cells that can be fused, said initial populations comprising at least 2 cells in each population, and at least two cells in each population having different combinations of heterologous genes and/or different combinations of expression cassettes, each cell comprising at least a first type of artificial chromosome, said at least first type of artificial chromosome comprising both at least two expression cassettes comprising heterologous genes and at least one selectable marker, the selectable markers being allocated to artificial chromosomes so that each type of artificial chromosome from each population can be individually selected for,

performing protoplast fusion and regeneration of cell walls or performing fusion of cells, and

selecting fused cells that carry at least a subset of the selectable markers present on the artificial chromosomes in the two initial populations.

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As for the first aspect of this invention, the second aspect provides a method for mixing and optimising gene combinations for expressible genes located on artificial chromosomes. The method may be used even in cases where it is not possible to mate cells in vitro.

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Preferably, the cells or protoplasts caused to fuse are haploid, so that the chromosome number of the fused cells is diploid. It is also possible in some species to fuse cells with higher ploidy level and thus obtain polyploid fused cells.

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The process may be repeated one or more times.

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Preferably the species of cells are selected from fungi, algae, and plants, for which protocols for isolation and fusion of protoplasts and subsequent regeneration of cell walls are known. More preferably, the species of cells is a fungus species, in which it is possible to induce spore formation in vitro. Other relevant species include prokaryotes, which can be fused.

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However, it is also contemplated, that it becomes possible to fuse animal cells, which do not have a cell wall, so that the species of cells may include animal cells, including human cells.

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Preferably, the species of cells is one for which extensive in vitro protocols are known, and for which standard molecular biology methods have been developed. These include industrial microorganisms, preferably fungi, more preferably yeast. Suitable examples of yeast species are disclosed in the detailed description of the present invention. Other species include carrot, *Arabidopsis thaliana*, *Nicotiana* spp., *Nicotiana tabacum*, maize, wheat, rice, soybean, tomato, peanut, potato, sugar beets, sunflower, yam, rape seed, conifers, and petunia. The list is expected to grow in future as the field expands.

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As for the mating based method, the mixing may advantageously be combined with screening cells that result from protoplast fusion for a desired functionality(ies) and selecting cells having the desired functionality(ies) above a defined threshold, isolating protoplasts from these cells and performing protoplast fusion and cell  
5 regeneration on the selected cells.

According to a further aspect the invention relates to a method for mixing heterologous genes in expression cassettes located on artificial chromosomes, said method comprising the steps of

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providing two initial populations of cells,  
said initial populations comprising at least 2 cells in each population, and at least two cells in each population having different combinations of heterologous genes and/or different combinations of expression cassettes,  
15 each cell comprising at least a first type of artificial chromosome, the at least first type of artificial chromosome comprising both at least two expression cassettes comprising heterologous genes and at least one selectable marker,  
the selectable markers being allocated to artificial chromosomes so that each type of artificial chromosome from each population can be individually selected for,  
20 mating the cells with each other,  
amplifying the artificial chromosomes in the host cells,  
isolating the artificial chromosomes,  
mixing the isolated artificial chromosomes,  
transferring subsets of said isolated and mixed artificial chromosomes into host  
25 cells, and  
selecting cells that carry at least a subset of the selectable markers present on the artificial chromosomes in the two initial populations.

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According to this aspect, use is made of the fact that artificial chromosomes can be amplified in the host cells, for example in yeast it is possible to use vectors that permit copy number amplification. The vectors include a conditional centromere that can be turned on or off. The disruption of the centromere activity by high levels of transcription towards conserved centromeric elements leads to a segregation bias during cell division wherein the mother cell receives both copies of the artificial  
35 chromosome, in this case a YAC. At the same time, a strong selective pressure for

extra copies of the artificial chromosome can be applied by selecting for the expression of a heterologous gene such as thymidine kinase. Selection for the TK gene can be accomplished by adding exogenous thymidine in the presence of methotrexate and sulfanilamide. The later two compounds inhibit enzymes involved in the recycling or de novo synthesis of folate cofactors required for the synthesis of deoxythymidilic acid. When this system is used, artificial chromosomes were readily amplified 10- to 20- fold. Reactivation of the centromere in amplified artificial chromosome clones resulted in stable maintenance of an elevated copy number (Smith et al, PNAS, 1990, vol 87:8242-46).

The method may advantageously be combined with the other gene mixing methods according to the invention, in particular with the mating based method, which in a preferred embodiment includes physical isolation of artificial chromosomes.

The host cells into which the subsets of mixed artificial chromosomes are transferred may already contain artificial chromosomes with expression cassettes with heterologous genes.

According to a further aspect of the invention there is provided a method of mixing heterologous genes in expression cassettes located on artificial chromosomes, said method comprising the steps of:

a) obtaining at least one population of cells, the cells of said at least one population comprising a concatemer of expression cassettes of the following formula:

$[rs_2\text{-}SP\text{-}PR\text{-}X\text{-}TR\text{-}SP\text{-}rs_1]_n$

wherein

$rs_1$  and  $rs_2$  together denote a restriction site,

SP individually denotes a spacer,

PR denotes a promoter, capable of functioning in the cells,

X denotes an expressible nucleotide sequence,

TR denotes a terminator, and

$n \geq 2$ ,

the cells differing from each other with respect to combinations of expressible nucleotide sequences and/or promoters and/or terminators and/or spacers,

- b) isolating at least some of the cassettes of the selected cells by cutting the concatemers with a restriction enzyme cleaving  $rs_1rs_2$ ,  
c) amplifying at least some of the isolated cassettes,  
5 d) assembling the expression cassettes of step c) into artificial chromosomes, and  
e) optionally transferring the artificial chromosomes into host cells.

10 In one embodiment of the invention, n is at least 10, such as at least 15, for example at least 20, such as at least 25, for example at least 30, such as from 30 to 60 or more than 60, such as at least 75, for example at least 100, such as at least 200, for example at least 500, such as at least 750, for example at least 1000, such as at least 1500, for example at least 2000.

15 The concatemers can be used to make novel and non-native combinations of genes for co-ordinated expression in a host cell. Thereby new metabolic pathways can be generated, which may lead to the production of new metabolites, and/or to the metabolisation of compounds, which are otherwise not metabolisable by the host cells. The new gene combinations may also lead to metabolic pathways which  
20 produce metabolites in new quantities or in new compartments of the cell or outside the cell. Depending on the purpose, the selection of genes can be made completely random based on sourcing of expressible nucleotide sequences across the different kingdoms. However, it may also be advantageous to source genes from sources known to have certain metabolic pathways in order to make targeted new gene  
25 combinations. It may also be advantageous to source genes from organisms/tissues known to have relevant properties, e.g. a specific pharmaceutical activity.

30 One of several advantages of the concatemers of the present invention is that the expression cassettes can be cut out from the concatemers at any point to make new combinations of expression cassettes. During re-assembly, further genes comprised in similar expression cassettes may be added if desired to modify the expression pattern. In this way, the concatemers according to the present invention present a powerful tool in generating novel gene combinations.



One advantage of the structure of the concatemer is that cassettes can be recovered from the host cell through nucleotide isolation and subsequent digestion with a restriction enzyme specific for the  $rs_1$ - $rs_2$  restriction site. The building blocks of the concatemers may thus be disassembled and reassembled at any point.

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The amplification step ensures that the copy number of the cassettes is high enough to be able to perform the re-assembly conveniently. The amplification step may include PCR with primers that tag  $rs_1$  and  $rs_2$  and/or inserting isolated cassettes into a vector having a cloning site compatible with  $rs_1rs_2$  and multiplying this vector in a suitable host.

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Further expression cassettes may be added for the assembly step if desired. Conveniently, the method may be combined with screening cells with assembled artificial chromosomes for a desired functionality(ies) and selecting cells having the desired functionality(ies). The process may be repeated by subjecting the selected cells to further isolation and amplification of cassettes and assembly of artificial chromosomes. The method may also be combined with any of the other gene mixing methods according to the invention.

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In a still further aspect the invention relates to a method for mixing expressible nucleotide sequences, said method comprising the steps of

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a) obtaining at least one population of cells, the cells of said at least one population comprising at least two expression cassettes of the following formula:

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$[rs_2$ -SP-PR- $rs_1'$ -X- $rs_2'$ -TR-SP- $rs_1]$

wherein

$rs_1$  and  $rs_2$  together denote a restriction site,

$rs_1'$  and  $rs_2'$  together denote a different restriction site,

SP individually denotes an optional spacer,

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PR denotes a promoter, capable of functioning in the cells,

X denotes an expressible nucleotide sequence,

TR denotes a terminator,

b) isolating at least some of the expressible nucleotide sequences of the selected cells by cutting the cassettes with a restriction enzyme cleaving  $rs_1'rs_2'$ , or by

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amplifying the sequences with primer pairs templating sequences in rs1' and rs2',

- c) re-inserting the expressible nucleotide sequences into other similar backbone,
- d) re-mixing the expression cassettes, and
- 5 e) transferring the re-expression cassettes into host cells.

The method provides a way of isolating the coding sequence for re-insertion into new expression constructs in order to increase the number of expression contexts.

- 10 Preferably, the isolated expressible nucleotide sequences are inserted into primary vectors comprising a nucleotide sequence cassette of the general formula in 5'→3' direction:

[RS1-RS2-SP-PR-CS-TR-SP-RS2'-RS1']

wherein

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RS1 and RS1' denote restriction sites,

RS2 and RS2' denotes restriction sites different from RS1 and RS1',

SP individually denotes a spacer sequence of at least two nucleotides,

PR denotes a promoter,

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CS denotes a cloning site,

TR denotes a terminator.

Expression cassettes can be isolated from these primary vectors and assembled into concatamers of expression cassettes with new gene combinations.

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In a further aspect the invention relates to a method of mixing heterologous genes in expression cassettes located on plasmids said method comprising the steps of providing two initial populations of cells that can mate with each other, said initial populations comprising at least 2 cells in each population, and at least two cells in each population having different combinations of heterologous genes and/or different combinations of expression cassettes, each cell comprising at least a first plasmid, the at least first plasmid comprising both at least two expression cassettes comprising heterologous genes and at least one selectable marker,

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the selectable markers being allocated to plasmids so that each type of plasmid from each population can be individually selected for, mating the cells with each other, and selecting mated cells that carry at least a subset of the selectable markers present on the plasmids in the two initial populations.

There are several advantages associated with having the expression cassettes located on a plasmid. Among these is the possibility of using a shuttle vector which makes it possible to amplify the plasmids in bacteria and later transform them into another cellular host, such as yeast. Plasmids may also be purified in bacteria by simply isolating total DNA from the host cells and transform this into bacteria. As only the plasmids have an origin of replication, which is functional in a bacterium, only the plasmids are replicated, and the plasmids are therefore selectively amplified. The selectable markers located on the plasmids are used to select for bacteria harbouring the plasmids. The plasmids can then be re-isolated from the bacteria and re-inserted into the other host cells.

Preferably, in the plasmid based method, the expression cassettes are located on a nucleotide concatemer comprising in the 5'→3' direction a cassette of nucleotide sequence of the general formula

$$[rs_2\text{-}SP\text{-}PR\text{-}X\text{-}TR\text{-}SP\text{-}rs_1]_n$$

wherein

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$rs_1$  and  $rs_2$  together denote a functional restriction site,  
SP individually denotes a spacer of at least two nucleotide bases,  
PR denotes a promoter, capable of functioning in a cell,  
X denotes an expressible nucleotide sequence,  
TR denotes a terminator, and  
SP individually denotes a spacer of at least two nucleotide bases, and  
 $n \geq 2$ , and  
wherein at least a first cassette is different from a second cassette.

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In a separate aspect of the invention there is provided a method for mixing of heterologous genes in expression cassettes located on artificial chromosomes or plasmids, wherein a biological selection pressure is used to ensure that only cells with the desired functionality(ies) survive this selection pressure. The biological selection pressure may e.g. be based on a reporter system which is transformed into the host cells prior to transformation of the artificial chromosomes or plasmids with the expression cassettes or it may be a medium based selection pressure or any of the other selection methods described in the present application. The biological selection pressure is applied as soon as possible after insertion of the artificial chromosomes or plasmids, just allowing the cells time to recover after the transformation. This method more closely resembles natural evolution of cells and will eventually cause cells to evolve the properties selected for. As with the other methods this method can be combined with any other method (mating, protoplast fusion, physical isolation) according to the present invention.

#### Definitions

Diploid type: A mated cell that contains at least one artificial chromosome from each parent population of a mating round. Depending on the number of artificial chromosomes in the parent populations, mating will result in many diploid types. The presence of artificial chromosome of type A and B in one parent population and type C and D in another results in the following diploid types: AC, AD, BC, BD, ABC, ABD, ACD, BCD, ABCD.

Fused cell type: a cell resulting from protoplast or cell fusion, which carries at least one artificial chromosome from each of the two populations that formed the fused cells. Depending on the number of artificial chromosomes in the two initial populations, fusion will result in many fused cell types. The presence of artificial chromosome of type A and B in one initial population and type C and D in another results in the following fused cell types: AC, AD, BC, BD, ABC, ABD, ACD, BCD, ABCD.

Protoplast: a cell from which the cell wall has been removed.

Artificial chromosomes: As used herein, an artificial chromosome (AC) is a piece of DNA that can stably replicate and segregate alongside endogenous chromosomes. For eukaryotes the artificial chromosome may also be described as a nucleotide sequence of substantial length comprising a functional centromere, functional telomeres, and at least one autonomous replicating sequence. It has the capacity to accommodate and express heterologous genes inserted therein. It is referred to as a mammalian artificial chromosome (MAC) when it contains an active mammalian centromere. Plant artificial chromosome and insect artificial chromosome (BUGAC) refer to chromosomes that include plant and insect centromeres, respectively. A human artificial chromosome (HAC) refers to a chromosome that includes human centromeres, AVACs refer to avian artificial chromosomes. A yeast artificial chromosome (YAC) refers to chromosomes that are functional in yeast, such as chromosomes that include a yeast centromere.

As used herein, stable maintenance of chromosomes occurs when at least about 85%, preferably 90%, more preferably 95%, more preferably 99% of the cells retain the chromosome. Stability is measured in the presence of a selective agent. Preferably these chromosomes are also maintained in the absence of a selective agent. Stable chromosomes also retain their structure during cell culturing, suffering neither intrachromosomal nor interchromosomal rearrangements.

Expression cassettes comprising heterologous genes: By the term "expression cassettes" is meant controllably expressed nucleotide sequences, of the formula:

PR-X-TR

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wherein

PR denotes a promoter, capable of functioning in a cell,

X denotes an expressible nucleotide sequence,

TR denotes a terminator, capable of functioning in a cell.

The promoter and expressible nucleotide sequence may be natively associated but preferably the promoter is heterologous to the expressible nucleotide sequence.

Selectable marker: any gene, which provides the cell with a function, for which selection can be made to ensure the presence of the selectable marker in the cell. Typical examples of selectable markers include auxotrophic markers and drug resistance markers. Further examples of selectable markers include markers giving

a colour or a particular morphology, which may be selected for in a flow cytometer or by hand. Still further examples of selectable markers include resistance against physical or chemical conditions, e.g. radiation resistance, salt resistance. These may be selected for on the basis of survival. Other types of markers include  
5 nucleotide probes labelled with a stain/dye molecule or preferably a fluorescent signal molecule.

### **Description of the drawings**

10 Fig. 1 shows one schematic example of mixing of genes using mating and selection. Different shades of the artificial chromsomes (native chromosomes left out) illustrate different types of artificial chromosomes.

15 Fig. 2 shows an example of multiple parameter screening for compounds synthesised by cells, where the compounds inhibit Cox-2 and NF- $\kappa$ B and do not inhibit Cox1. It is shown that in early rounds, cells that meet one, two or all three of the criteria are selected. In later rounds, only cells that fit all the selection criteria are selected.

20 Fig. 3 shows an example of a multiple parameter screen including *S. Aureus* growth inhibition, DNA Polymerase III inhibition and P450 compound inactivation. The screen is assembled by, for example, transforming a library of producer strains with GFP reporter systems for a few selected human P450s and for recombinant *Bacillus subtilis* DNA Pol III. The library is then plated and overlaid with an MRSA strain.  
25 The compounds have to cross the producer's cell wall and reach the MRSA strain thus the screen will also select for compounds that have a reasonable solubility profile. Producer cells in zones cleared of MRSA cells and which produce the desired combination of fluorescent colours are selected.

30 Fig. 4a illustrates a multiple parameter screen set-up for cancer chemoprotectant. In the assay, a producer species library is encapsulated so that on average each capsule has 1 cell and allow to grow for a few generations. These clonal lines are then double encapsulated with a permeabilised yeast that contains a human DNA Topo II  $\alpha$  reporter system. The gel droplet environment contains etoposide (a

poison) and a fluorescent DNA double strand break stain. Gel droplets where the yeast cells in the outer layer have survived and that do not fluoresce are selected.

Fig. 4b illustrates a method of screening single yeast cells. Cells were encapsulated in alginate beads (diameter 20  $\mu$ ). Beads were inoculated into selective medium and cells allowed to grow for c. 6 generations resulting in each bead containing c. 100 clonal cells. Beads were then placed in inducive medium for 24 h before co-encapsulation w. reporter yeast. The reporter yeast cells were *S. cerevisiae* strains JN394 and JN 394top2-5 ( Nitiss and Nitiss(2001), Methods Mol Biol.;95:315-27 ). JN394 -deGFP(ise2 and RAD52 mutant) DNA repair deficient and hypersensitive to Topo2 poisons, expresses deGFP constitutively. JN394top2-5-deCFP (contains a TOPO 2 that is resistant to topo-poisons), expresses deCFP constitutively. Double encapsulation beads were then placed in selective medium containing a lignan precursor and incubated for 8 hours. Geldroplets showing CFP fluorescence but no GFP fluorescence were selected and producer cells retained for further evolution. Gel droplets shoving no fluorescence, or double fluorescence were discarded.

Fig. 5 shows a multiple parameter screen set up where a producer species library reporting RXR-RXR activation is co-encapsulated with a mammalian cell line reporting PPAR $\gamma$ -RXR activation as well as P450 compound inactivation. Gel droplets that indicate PPAR $\gamma$ -RXR activation but not RXR-RXR or P450 inhibition are selected.

Fig. 6 shows an example of a multiple parameter screen for absorption and a pharmacological activity: By using a dual culture system and timing the time of cell selection, it is possible to select producer cells that have the desired pharmacological activity and a good absorption profile.

Fig. 7 shows an example of a screening system which minimises the number of false positives generated by compounds that are rapidly metabolised by the human DMEs and also leads to the discovery of compounds that are active after being metabolised and which would otherwise remain undiscovered.

Fig. 8 shows a schematic representation of a screening system of the present invention to evaluate target activity, metabolism by DMEs and cytotoxicity: Using a

double gel encapsulation system where in the first droplet are clonal lines of the producer species transformed with the pharmacological target and DMEs, and in the second droplet are hepatocytes, it is possible to screen for target activity, DME metabolism and hepatotoxicity.

5

Fig. 9 shows a flow chart of the steps leading from an expression state to incorporation of the expressible nucleotide sequences in an entry library (a nucleotide library according to the invention).

10

Fig. 10 shows a flow chart of the steps leading from an entry library comprising expressible nucleotide sequences to evolvable artificial chromosomes (EVAC) transformed into an appropriate host cell. Fig. 10a shows one way of producing the EVACs which includes concatenation, size selection and insertion into an artificial chromosome vector. Fig. 10b shows a one step procedure for concatenation and

15

ligation of vector arms to obtain EVACs.

20

Fig. 11 shows a model entry vector. MCS is a multi cloning site for inserting expressible nucleotide sequences. Amp R is the gene for ampicillin resistance. Col E is the origin of replication in E. coli. R1 and R2 are restriction enzyme recognition sites.

25

Fig. 12 shows an example of an entry vector according to the invention, EVE4. MET25 is a promoter, ADH1 is a terminator, f1 is an origin of replication for filamentous phages, e.g. M13. Spacer 1 and spacer 2 are constituted by a few nucleotides deriving from the multiple cloning site, MCS, SclI and Ascl are restriction enzyme recognition sites. Other abbreviations, see Fig. 11. The sequence of the vector is set forth in SEQ ID NO 1.

30

Fig 13 shows an example of an entry vector according to the invention, EVE5. CUP1 is a promoter, ADH1 is a terminator, f1 is an origin of replication for filamentous phages, e.g. M13. Spacer 1 and spacer 2 are constituted by a few nucleotides deriving from the multiple cloning site, MCS, SclI and Ascl are restriction enzyme recognition sites. Other abbreviations, see Fig. 11. The sequence of the vector is set forth in SEQ ID NO 2.

35



Fig 14 shows an example of an entry vector according to the invention, EVE8. CUP1 is a promoter, ADH1 is a terminator, f1 is an origin of replication for filamentous phages, e.g. M13. Spacer3 is a 550 bp fragment of lambda phage DNA fragment. Spacer4 is a ARS1 sequence from yeast. SclI and AscI are restriction enzyme recognition sites. Other abbreviations, see Fig. 11. The sequence of the vector is set forth in SEQ ID NO 3.

Fig. 15 shows an example of an entry vector according to the invention, EVE9. Met25 is a promoter, ADH1 is a terminator. Spacer 5 and 6 are lambda phage DNA. SEQ ID NO 5.

Fig. 16 shows a vector (pYAC4-AscI) for providing arms for an evolvable artificial chromosome (EVAC) into which a concatemer according to the invention can be cloned. TRP1, URA3, and HIS3 are yeast auxotrophic marker genes, and AmpR is an E. coli antibiotic marker gene. CEN4 is a centromere and TEL are telomeres. ARS1 and PMB1 allow replication in yeast and E. coli respectively. BamH I and Asc I are restriction enzyme recognition sites. The nucleotide sequence of the vector is set forth in SEQ ID NO 4.

Fig. 17. shows the general concatenation strategy. On the left is shown a circular entry vector with restriction sites, spacers, promoter, expressible nucleotide sequence and terminator. These are excised and ligated randomly.

Lane	F/Y
1	100/1
2	50/1
3	20/1
4	10/1
5	5/1
6	2/1
7	1/1
8	1/2
9	1/5

Legend: Lane M: molecular weight marker,  $\lambda$ -phage DNA digested w. Pst1. Lanes 1-9, concatenation reactions. Ratio of fragments to yac-arms(F/Y) as in table.

Fig 18a and 18b. illustrates the integration of concatenation with synthesis of evolvable artificial chromosomes and how concatemer size can be controlled by

controlling the ratio of vector arms to expression cassettes, as described in example 14.

Fig 19. EVAC gel Legend: PFGE of EVAC containing clones :

5 Lanes. a: Yeast DNA PFGE markers(strain YNN295), b: lambda ladder, c: non-transformed host yeast, 1 – 9 : EVAC containing clones. EVACs in size range 1400-1600 kb. Lane 2 shows a clone containing 2 EVACs sized ~1500 kb and ~550 kb respectively. The 550kb EVAC is comigrating with the 564kb yeast chromosome and is resulting in an increased intensity of the band at 564 kb relative to the other  
10 bands in the lane. Arrows point up to EVAC bands.

Fig. 20 shows an example of generation of an EVAC containing cell population. EVACs (Evolvable Artificial Chromosome) are artificial chromosomes composed of concatemers of expression cassettes containing heterologous DNA, so that each  
15 gene is under the control of an externally controllable promoter. Large numbers of heterologous genes from multiple sources can thus be combined in a single host cell.

Fig. 21 shows the general principle for screening EVAC containing cell populations. The cell population is amplified and subjected to a panel of screens that are relevant  
20 to a desired functionality. Positive subpopulations are selected.

Fig. 22 shows how cell populations evolve through a tiered set of selection conditions, always taking the best performing cell populations further in the process until  
25 an optimal functionality/property is evolved.

Fig. 23 shows a general screening strategy. Independent populations are subjected to the same set of screens, and genetic material from the different selected subpopulations is combined together with novel genetic diversity introduced between  
30 selection rounds.

Fig. 24 shows physical remixing of EVACs. EVACs are isolated from the host and used for transformation of either empty host cells or for transformation of host cells already containing EVACS to obtain new combinations of EVACs in each host cell.  
35

Fig. 25 shows one example of evolution. Cells that are resistant to a poison may be selected in liquid media. The surviving cells are cells containing EVACs that result in the production of compounds that prevent the poison from interacting with its target.

5 Fig. 26 shows how an evolution programme based on a screen for compounds that activate (or prevents) activation of a reporter system may be designed. Using the appropriate marker (e.g. GFP) positive clones can be selected using e.g. flow cytometry.

10 Fig. 27 shows an example of controllable gene expression in a cell population containing EVACs enriched in genes that code for carotenoid synthetic enzymes. The expression cassettes contain either a Met 25 or a CUP I promoter. Orange, yellow and red colonies are obtained as a function of the promoter activation. Intensity of colour and number of coloured colonies increases in the following order: CUP + Met  
15 > CUP > Met. Uninduced colonies are white.

Figure 28 shows oxidative stress resistance of cells after 1, 2 and 3 rounds of screening. CEY (compound enhanced yeast) indicate selected yeast cells.

20 Figure 29 shows yeasts producing pink, yellow, orange and green colours obtained after two and three rounds of screening. CEY (compound enhanced yeast) indicate selected yeast cells.

Figure 30 shows the carotenoid content of 10 selected yeast clones. CEY (compound enhanced yeast) indicate selected yeast cells.  
25

### Detailed Description of the Invention

30 The following provides a background description on how to apply the gene mixing methods according to the invention and how to use these in the directed to evolution of cells to acquire new functionalities.

35 The present invention relates to methods of mixing of genes for the purpose of evolving cells having at least one desired functionality, preferably evolving cells that

produce compounds, novel substances and/or comprise novel metabolic pathways. The mixing and/or evolution may lead to the production of novel molecules of commercial value, such as pharmaceuticals, cosmetics, flavours, other food and animal feed ingredients, agricultural chemicals, colouring agents, diagnostic markers, industrial chemicals and intermediates for industrial purposes.

By "Evolution of a cell" is meant change of a cell's phenotype towards a novel phenotype due to expression of a novel combination of genes. By "evolution of a composition" is meant change of the properties of a composition due to a novel combination of cells expressing a novel combination of genes.

In the following the term mixing is mainly used for describing the assembly of expression cassettes and the term remixing is mainly used for the process referring to further mixing of expression cassettes as described in the claims. However, as both terms encompass mixing, the term mixing is also used for the remixing steps.

In seeking to evolve molecules with defined pharmaceutical, industrial, nutritional properties one must have a method of selecting for those genetic patterns that encode for phenotypes that are consistent with these properties.

Each cell in a cell population, given that it is genetically different from other cells, has an intrinsic variability that can potentially express itself in one or more ways. For the purposes of the current invention the term Output shall be taken to mean a property of the cell that is consequent to the expression of one or more expression cassettes. Optionally the property may be consequent to both the expression of one or more expression cassettes and the expression of a certain set of host genes.

Outputs can be measured according to various different criteria. These criteria may be directly or indirectly linked to the functional or structural properties that are being optimised. Alternatively they may be inversely linked to functional or structural properties that are not desired.

Outputs can be measured either directly or by means of a reporter construct. For the purposes of this document the term Reporter Construct shall be taken to mean a genetic or molecular device for measuring whether a given cell or subset of cells in a

cell population vary in respect of a given output from other cells or subsets of cells in the cell population. Example reporter constructs include a genetic construct that produces a fluorescent protein in response to the activation of a transcription factor by an output. Another example of a reporter construct is a coloured enzyme substrate, to which an enzyme is added that converts the substrate to another molecule with a different colour. Should the cell produce an output that inhibits the enzyme, the colour change will not occur.

Outputs that can be measured without a reporter construct include without limitation the survival of cells subjected to the screening criteria, cells able to metabolise a predetermined substance, cells able to produce a substance that preferentially absorbs electromagnetic radiation at one or more frequencies, cells having enzymatic efficacy in the media etc.

Reporter constructs can be placed proximal either before or after the expression construct is engineered into the cell. Methods of incorporating the reporter construct into a proximal location include but are not limited to standard transformation techniques, the mating of two different yeast mating types, or systems providing physical proximity between cell and reporter construct, for example gel microdroplet co-encapsulation of cell and reporter construct.

The term Proximal shall be taken to mean a location that is either in the same cell as the expression construct or sufficiently close to said cell such that the concentration of a molecule or molecules diffusing from an intact or lysed cell, or being actively pumped from the cell, is at least one picomole in the vicinity of the location

Outputs of cells that may be measured either by proximal reporter constructs or by other means include, but are not limited to:

- Novel spectral properties
- Induced cytochrome oxidase activity
- Changed size, morphology, stickiness or adhesive properties or lack thereof
- Ability to grow on substrates they cannot normally grow on
- Ability to grow on sublethal substrates
- Ability to grow in the absence of normal essential requirements
- Ability to grow on media comprising one or more inhibitors

- Ability to grow under changed physical conditions, such as temperature, osmolarity, electromagnetic radiation including light of certain wavelengths.
- Ability to grow under magnetic field of certain force.
- Secretion or the lack of it from the cell
- 5     • The inhibition or prevention of inhibition of an enzyme
- The activation of a receptor.
- The prevention of an activating molecule binding to a receptor.
- The inhibition or promotion of binding of small molecules or proteins to nucleic acid or peptide sequences.
- 10    • The inhibition or promotion of transcription or translation of post translational processing.
- Changes in the transport or localisation of molecules within the cell or within organelles.
- Changes in the DNA content or morphology of the cell.
- 15    • The production of small molecules with certain properties that allow their selective isolation (e.g. all the chromatography principles available to the skilled practitioner).
- The production of small molecules with certain spectroscopic properties (defined broadly to include visible light, microwaves, IR, UV, X-ray, etc.).
- 20    • Changes in the morphology of the cell, including the prevention or promotion of cell differentiation.
- The induction of apoptotic pathways.
- Chemical indicator.

## 25     **Diverse Genetic Patterns**

Given that evolution is a statistical process it is necessary to provide sufficient genetic variation on which selection processes can act. In the present invention, this comprises two elements

- 30     • Providing a sufficiently large and diverse population
- Controlling the genetic basis of the diversity and how it expresses

Selection requires genetic diversity on which to operate. Thus the first requirement of the current invention is to provide a population of cells that embodies a genetic

35     diversity. The term "*genetic diversity*" means that substantially all cells are different,

in that they comprise different genes, and/or identical genes under control of different control system, such as different promoters, such that almost each cell initially represents a genotype not represented in any of the other cells. Of course due to cell division a few cells may be substantially identical.

5

The term "Cell Population" shall be taken to mean a population of cells where at least  $10^4$  cells, such as at least  $10^5$  cells, such as at least  $10^6$  cells, such as at least  $10^7$  cells, such as at least  $10^8$  cells, such as at least  $10^9$  cells, such as at least  $10^{10}$  cells, such as at least  $10^{11}$  cells, such as at least  $10^{12}$  cells in the population  
10 represent a genotype not represented in any of the other cells.

Thus, the principle of the evolution method according to the invention is to obtain a population of cells having a very high genetic diversity.

15

One particular embodiment of this principle is to produce cells with combinations of concatemers comprising cassettes with expressible nucleotide sequences from a number of different expression states, which may be from any number of unrelated or distantly or closely related species, or from species from different kingdoms or phylae, novel and random combinations of gene products are produced in one  
20 single cell.

20

By inserting novel genes into the host cell, and especially by inserting a high number of novel genes from different expression states, such as from a wide variety of species into a host cell, the gene products from this array of novel genes will interact with the pool of metabolites of the host cell and with each other and modify known  
25 metabolites and/or intermediates in novel ways to create novel compounds. Due to the high number of substantially different cells that can be generated using the methods according to the present invention, for example at least  $10^4$  cells, such as at least  $10^5$  cells, such as at least  $10^6$  cells, such as at least  $10^7$  cells, such as at least  $10^8$ , such as at least  $10^9$ , for example at least  $10^{10}$ , such as at least  $10^{12}$ , it is  
30 more or less inevitable or at least likely that such large populations will lead to a sub-population having such an interaction. The sub-population having such interaction may comprise at most  $10^{10}$  cells, such as at most  $10^9$  cells, such as at most  $10^8$ , such as at most  $10^7$  cells, such as at most  $10^6$  cells, such as at most  $10^5$  cells, such as at most  $10^4$  cells, such as at most  $10^3$  cells, such as at most  $10^2$  cells  
35 or just 10 cells.

35

### Generation of Novel Genetic Compositions

5 It is a requirement of evolutionary processes that new patterns are generated either in parallel to or sequential to selection steps. In systems where the patterns are based on genetic elements this requires that either new genetic elements are introduced or new combinations of existing genetic elements are created or both.

10 In the present invention new patterns can be achieved through one or more of the following processes. The term combining or remixing shall be taken to mean a process of generating new combinations of expression constructs using one or more of these approaches. The combination or remixing may be conducted at any step of the selection process and a preferred timing is when cells having elements of the predetermined functionality have been found in at least one of the compositions, and  
15 preferably in at least 0.1%, such as at least 1%, such as at least 2%, such as at least 5%, such as at least 10% or at least 50% of compositions. The term Daughter Population shall be taken to mean a cell population that is predominately genetically descendant from those cells in one or more cell populations that had a fitness score above a certain threshold and that is further characterised by most of the cells in the  
20 daughter population having been generated through a remixing step.

In principle the combination or remixing may be conducted by at least the following approaches: physical isolation and remixing of expression cassettes, physical isolation and remixing of artificial chromosomes containing expression cassettes,  
25 sexual crosses, cell- or protoplast fusion (vide Hugerat Y, Spencer F, Zenwirth D, Simchen G (1994). Genomics 22(1), p. 108-117), and YAC-duction (vide Curran BP, Bugeja VC (1996), Methods Mol. Biol. 53, p 45-49.

30 Physical isolation of the expression cassettes and subsequently mixing the cassettes may be used together with the mating and protoplast/cell fusion methods of the present invention. One advantage of this approach is that any accumulating host mutations are removed by the remixing of genes into new host lines. Reporter genes can also be introduced as part of this process, allowing for the introduction of intracellular reporter assays. The remixing is preferably carried out in vitro by  
35 removing the expressible sequences from at least two different cells, combining the



individual expressible sequences in vitro, and introducing at least two combined expressible sequences into at least two cells.

5 Due to the common structure of the expression cassettes according to a preferred embodiment of the invention, these may easily be excised from the host cells again using a restriction enzyme specific for the  $rs_1$ - $rs_2$  restriction site. According to the present invention the enzyme specific for the  $rs_1$ - $rs_2$  restriction site is preferably a rare cutter therefore the likelihood of cutting host genomic DNA fragments with a size similar to the size of the expression cassettes is very limited. After excision the  
10 expression cassettes may be mixed with other expression cassettes of similar structure and be re-concatenated and re-inserted into another host cell in another combination creating a greater diversity during the evolution steps.

15 The combination of expressible sequences may of course also be a combination of full length chromosomes in the cells, such as combination of artificial chromosomes. Combination of the artificial chromosomes may be achieved in at least 4 ways depending on the host cells. These are physical isolation, crosses, protoplast fusion and YAC-duction as described herein.

20 An alternative way of physically remixing expression cassettes is to isolate the artificial chromosomes from one or more cell populations and re-transform new host cells. The host cells may or may not already contain artificial chromosomes containing expression cassettes.

25 **Addition of new genetic material.**

The remixing is preferably conducted with addition of new genetic material from another cell composition. The other composition may be chosen from compositions capable of expressing at least one predetermined phenotype, such as a protein or a  
30 metabolite, or it may be chosen at random.

In one embodiment it is desirable to conduct selection in a series of isolated populations that are then brought together once they have independently evolved useful traits. In this manner the use of independent selections for same phenotype

provides different genetic backgrounds (a form of parallel evolution) that can then ideally act synergistically with each other.

5 In another embodiment the result of selection on two or more compositions is mixed at a certain step of evolution to create further modified compositions when aiming for at least one cell having the desired functionality.

10 Recombination of the expressible sequences, i.e. changes of the genetic material by for example cross-over, may be optionally avoided, due the construction of the genetic inserts, in particular spacer sequences, as well as due to a general attempt to suppress recombination in the cells. Thereby combination of the genetic material is favoured, leading to combination of intact genes or cDNA material, without the risk of destroying the function of the genetic material due to recombination.

15 After having obtained daughter populations exhibiting the desired functionality, the daughter population may then be subjected to further steps of screening and selection in order to optimise the cells.

#### 20 **Novel Molecules and Pathways**

The aim of the evolution method according to the present invention is to evolve cells capable of producing new substances, such as new metabolites, new proteins, and/or having new pathways.

25 Thus, in a further aspect the present invention relates to a substance produced by the cells evolved according to the present invention, said substance being metabolites, proteins, carbohydrates, poly- and oligosaccharides, and ribonucleic acids. Since some of the interactions that produce the novel phenotypes are mediated by enzymes it is likely that the result will include novel compounds with  
30 chiral centres, which are especially difficult to produce via chemical synthesis.

Creation of novel pathways, may lead to the capability of creating cells capable of metabolising, i.e. converting, a compound, which is not metabolisable by the native, un-evolved cell. Thus, in particular the substance is a metabolite.

35

## MULTIPLE PARAMETER SCREENING

5 For a compound to be useable as a drug it must fulfil multiple functional requirements. It must interact with the target(s) and affect the function of the target in the desired manner. At the same time it should not interact with many other (often similar) targets, have major non-specific effects. And then it must further have the right physical-chemical parameters and be metabolised by the body in an acceptable manner.

10 Because of this intrinsic difficulty and complexity, the process of discovering and developing drugs has a very poor success rate and is thus extremely expensive (\$600mn per successful compound) and very time consuming (c. 8-12 years from discovery to clinic). Only c. 1 in 15 primary screens produce a compound that makes it into pre-clinical development and only 1 in 10 of these compounds then make it to  
15 market. The average pharmaceutical company spends 250 man-years of research and development effort for every compound that enters the clinic. Most pharmaceutical companies are, in consequence, failing to launch new drugs at the rate they require to satisfy their investors.

20 An alternative to the current process is the evolution of small molecules compounds towards multiple properties simultaneously, with these properties being related, either directly or indirectly to the therapeutic target(s) the small molecule has to interact with, the targets it should not interfere with, the ADMET properties it should fulfil, etc.

25

### ***Multiple Pharmacological Activities***

Due to the vast number of known targets and relationships between those targets that are currently known, it is not in the scope of the present invention to describe all  
30 know targets and their correlations. Table 1 discloses a list of relevant pharmacological targets.

Table 1: Drug targets

3 $\beta$  hydroxysteroid dehydrogenase  
3-hydroxy-3-methylglutaryl coenzyme A  
5-adenosyl homocysteine hydrolase  
5-HT<sub>3</sub> receptor

5-HT<sub>4</sub> receptor  
23S rRNA of the 50S ribosomal unit  
30S rRNA from 50S ribosomal unit  
50S ribosomal unit binding site

$\alpha$ 2 antiplasmin  
 $\alpha$ -adrenergic receptor  
 $\alpha$ -subunit of Na<sup>+</sup>/K<sup>+</sup> ATPase (3 isoforms)  
 $\alpha$ -amylase  
 $\alpha$ -glucosidase  
ACTH receptor  
Adenosine deaminase  
Adrenocortical steroid synthesis  
Adrenocorticosteroid receptor  
Adrenergic receptor  $\beta_1$ ,  $\beta_2$   
Adrenocorticotrophic hormone  
Androgen receptor  
Angiotensin-converting enzyme (ACE)  
Angiotensin II formation  
Angiotensin II receptor  
Antiplatelet/antithrombotic agent  
Arginine vasopressin receptor  
Angiotensin receptors, AT1, AT2  
ATP-sensitive K<sup>+</sup> channel  
Antigcoagulant protein C  
Antigcoagulant protein S  
Androgen receptor  
Apoptosis  
Aminoacyl tRNA site on 30S ribosomal unit (tetracycline)  
Acetylcholinesterase  
Adrenergic receptors  $\alpha_1$ ,  $\alpha_2$ ,  $\beta_1$ ,  $\beta_2$ ,  $\beta_3$   
Aromatase  
ATP sensitive K<sup>+</sup> channels  
Ascorbic acid

$\beta$ -amyloid  
 $\beta$ -adrenergic receptor  
 $\beta$ -lactamase  
 $\beta$ -subunit of DNA-dependent RNA polymerase  
 $\beta$ -adrenergic receptors,  $\beta_1$   
 $\beta$ -tubulin subunit of microtubules  
Benzodiazepine receptor  
Butyrylcholinesterase  
Bradykinin receptors, B<sub>1</sub>, and B<sub>2</sub>

Carbonic anhydrase, type IV, II  
Ca<sup>2+</sup> channel  
Ca<sup>2+</sup> channel, Voltage-activated T-type  
Catechol-O-methyltransferase  
Calcitonin  
Cell surface receptors for sulfonylureas on pancreatic  $\beta$  cells  
*Cell surface receptors for glitinides on pancreatic  $\beta$  cells*

Cholecystokinin (CCK<sub>A</sub>, CCK<sub>B</sub>)  
Choline acetyltransferase  
Cholinesterase  
Camitine  
Calcineurin  
Corticosteroid nuclear receptor  
Cyclophilin, cyclosporin binding protein  
CD<sub>3</sub> glycoprotein on T lymphocytes  
*CD33 receptor*  
*CD20 receptor*  
CG-rich DNA (actinomycin)  
Coagulation factor II, VII, IX, X  
Corticosteroid adrenocorticotropin receptors  
Cyclooxygenase 1, 2 (COX-1, COX-2)  
Cyclic nucleotide phosphodiesterase  
Cyclooxygenase  
Cytochrome P450 reductase  
Cytochrome P450 11 $\beta$  (11 $\beta$  hydroxylase)  
Cytochrome P450 17 $\alpha$  C17-20 lyase  
Cytochrome P450 aldo, aldosterone synthase  
Cytochrome P450 side chain cleavage (scc) enzyme  
Cytochrome P450-dependent sterol 14  $\alpha$ -demethylase

D-alanyl D-alanine synthetase  
Dihydropteroate synthetase  
Deoxycytidine kinase  
Dihydroorotate dehydrogenase  
Dihydrofolate reductase  
Dopamine D1-D5 receptors  
DNA chain elongation factor  
DNA cross-linking  
DNA-dependent RNA polymerase  
DNA gyrase, subunit  $\alpha$   
DNA methylation  
DNA polymerases I-III  
DNA primase  
DNA topoisomerase  
DNA alkylation  
DNA topoisomerase I, II and/or IV  
DNA alkylation (oxamniquine)

Erythropoietin  
Endo- $\beta$ -d-glucuronidase  
Estrogen receptor

Factors VII; VIII  
Fusion protein (respiratory syncytial virus)  
FKBP, tacrolimus binding protein, FK506 binding protein  
Folic acid  
Follicle-stimulating hormone (FSH)  
FSH receptor

Glycerol phosphate oxidase  
GABA<sub>A</sub> receptor (6 $\alpha$  variants, 3 $\beta$ , 2 $\delta$ , 3 $\gamma$  variants)  
GABA transaminase  
GABA<sub>A</sub>-associated ion channel  
Glutamic acid decarboxylase  
Glutamate/aspartate receptors, AMPA, GLU 1-4, KA, GLU 5-7, NMDA 1,2<sub>A-D</sub>,  
mGLU 1-7  
Glycinamide ribonucleotide transformylase  
Granulocyte colony-stimulating factor receptor  
GHRH receptor  
*Glucagon receptor*  
Glucoamylase  
Glucocorticoid receptor (GR)  
GnRH receptor  
Gonadotropin releasing hormone (GnHR)  
Guanylyl kinase  
G-protein coupled adenosine receptor  
Ganglionic adrenergic neurons/norepinephrine transporter  
Guanylate cyclase (nitroprusside)  
Guanylyl cyclase (NO)  
Granulocyte colony-stimulating factor  
Granulocyte-macrophage colony-stimulating factor  
Growth hormone receptor  
Growth hormone-releasing hormone (GHRH)  
Glycine receptor  $\alpha$ ,  $\beta$

H<sup>+</sup>, K<sup>+</sup> ATPase, proton pump  
H<sub>1</sub> histamine receptor  
H<sub>2</sub> histamine receptor  
HCl secretion by gastric cells  
Helicase  
HIV Protease  
HSV thymidine kinase  
Hemoglobin protease  
Heparin antagonist  
Hypoxanthine-guanine phosphoribosyl transferase  
*Her-2 receptor*  
Histamine receptors H<sub>1</sub>, H<sub>2</sub>, H<sub>3</sub>  
Hepatic sulfotransferase as a catalyst

Intercellular adhesion molecule 1  
Interleukin 1 receptor  
Interleukin (IL-1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11, -12)  
Interleukin-2 receptor  
IGF-1 receptor, IGF-2 receptor  
Iodothyronine-59-deiodinase, type 1, type 2  
Influenza A virus M<sub>2</sub> protein  
Inosine 5' phosphatidehydrogenase  
Insulin-like growth factor 1  
Interleukin-2-receptor

Inosinate dehydrogenase  
Interferon  $\alpha$   
Interferon  $\alpha$  receptor  
Inosine monophosphate dehydrogenase  
Integrase  
Interferon  $\alpha$   
Interferon  $\alpha$  receptor  
Interferon  $\gamma$   
Insulin  
Insulin-like growth factor (IGF-1, IGF-2)  
Insulin receptor,  $\alpha$  and  $\beta$  subunits  
Insulin transporter

Kallikrein, aprotinin, C-esterase,  $\alpha$ 2 macroglobulin  
Kinin

L-alanyl racemase  
L-aromatic amino acid decarboxylase  
L-type voltage-sensitive  $\text{Ca}^{2+}$  channel  
Leukocyte integrins  
Leukotriene A hydrolase  
Leukotriene  $\text{B}_4$  receptor  
Leukotriene  $\text{C}_4$  receptor  
Leukotriene C synthase  
Leukotriene  $\text{D}_4/\text{E}_4$  receptor  
Lipocortin (protein), inhibits phospholipase  $\text{A}_2$   
Lipoxygenases (12-lipoxygenase (platelets), 5-lipoxygenase (leukocytes))  
LH/choriogonadotropin (CG) receptor  
Luteinizing hormone (LH)  
Lactamase  
Lipoprotein lipase

$\text{M}_1$  receptor, muscarinic cholinergic  
 $\mu$  and  $\delta$  receptor in gastrointestinal tract  
Macrophage colony-stimulating factor  
Microbial dihydrofolate reductase  
Microtubular protein  
Mineralocorticoid receptor  
Mineralocorticoid receptor (MR)  
Monoamine oxidase (MAO)-A  
Monoamine oxidase (MAO)-B  
Muscarinic receptor,  $\text{M}_1$ , 3 subunits  
Muscarinic receptor,  $\text{M}_2$ , 3 subunits  
Muscarinic receptor,  $\text{M}_3$ , 3 subunits  
Muscarinic receptor,  $\text{M}_4$ , 3 subunits  
Mycobacterial RNA polymerase

N-acyl hydrolase  
 $\text{Na}^+$  channel,  $\alpha$ 1,  $\beta$ 1,  $\beta$ 3  
 $\text{Na}^+$  channel  $\alpha$ ,  $\beta$ ,  $\gamma$   
 $\text{Na}^+/\text{Cl}^-$ -symporter  
 $\text{Na}^+/\text{K}^+/\text{2Cl}^-$ -symporter

Niacin receptor  
Nicotinic acid  
Nicotinic receptor  
Nicotinic cholinergic receptors, muscle  $N_M$   $\alpha$ ,  $\beta$ ,  $\delta$ ,  $\gamma$ ,  $\epsilon$   
Nicotinic cholinergic receptors, neuronal,  $N_N$   $\alpha 2$ ,  $\alpha 3$ ,  $\alpha 4$ ,  $\alpha 5$ ,  $\alpha 6$ ,  $\alpha 7$ ,  $\alpha 8$ ,  $\alpha 9$ ,  $\beta 2$ ,  $\beta 3$ ,  $\beta 4$   
Neuramidase  
Neuropeptide Y, Y1, Y2 receptors  
Noradrenaline transporter

Opioid receptors  $\mu_{1-2}$ ,  $\delta_{1-2}$ ,  $\kappa_{1-3}$   
Oxytocin & receptor

Platelet-derived growth factor  
Parathyroid hormone (PTH)  
Peroxidase  
Progesterone receptor  
Prolactin  
Prolactin receptor  
Parasite  $\beta$ -tubulin  
Parasite dihydrofolate reductase  
Parasite glutamate gated  $Cl^-$  channel  
Penicillin-binding protein 1a (PBP 1a, 1b), transpeptidase  
PBP 2a, 2b  
PBP 3, 4, 5, 6, 7  
Platelet glycoprotein IIb/IIIa (fibrinogen receptor)  
Plasma protein transferrin ( $\beta 1$  glycoprotein)  
Pyridoxine receptor  
Penicilloyl enzyme  
Peptidyl site of the 50S ribosomal unit  
Primase  
Phosphodiesterase (type IV, cyclic nucleotide phosphodiesterase)  
Phospholipase  $A_2$ , C  
Platelet-activating factor  
Prostacyclin synthase  
Plasmodial heme polymerase  
Progesterone receptor  
Pyridoxine  
Phospholipase  $C\beta$   
Purine receptors,  $P_1$  ( $A_{1,2a,2b,3}$ ),  $P_{2X}$ ,  $P_{2Y}$   
Peroxisome proliferator-activated receptor  
Pancrelipase  
Potassium channel  
Prostaglandin 15-OH dehydrogenase  
Prostaglandin D-DP receptor  
Prostaglandin E1, E2, E3-EP receptor  
Prostaglandin F-FP receptor  
Prostaglandin I2-IP receptor  
Prostaglandin  $I_2$  ( $PGI_2$ ) receptor  
Prostaglandin  $F_2$  receptor  
Prostaglandin synthetase  
Prostaglandin  $I_2$  receptor



Reverse transcriptase  
Ribosomal protein from 50S ribosomal unit (streptomycin)  
Rh 0  
Riboflavin receptor  
Retinoic acid  $\alpha$ , X receptors  
Ribonucleoside diphosphate reductase  
Ribonucleotide reductase

Somatostatin  
Somatostatin receptors, several  
Steroid 5  $\alpha$  reductase 1, 2  
Sucrase  
Squalene epoxidase  
Stem cell factor, c-kit ligand  
Serotonin receptors (5-HT) 5-HT<sub>1A-F</sub>, 5-HT<sub>2A-C</sub>, 5-HT<sub>3</sub>, 5-HT<sub>4-7</sub>  
Succinic semialdehyde dehydrogenase  
Spindle formation  
Scission of DNA  
Secretion of vasopressin K receptor

Topoisomerase I, II, III, IV  
Tubulin  
Thrombopoietin  
Thrombin  
Tissue plasminogen activator  
Thymidylate synthetase  
Tachykinins, NK1, NK2, NK3  
Tryptaminergic receptor  
Thromboxane A<sub>2</sub> TP receptor, platelet and non-platelet  
Thromboxane synthase  
Thyroid-stimulating hormone (TSH) receptor, TR $\alpha$  1,2, TR $\beta$  1,2  
Tumor necrosis factor receptor  
Trypanothione reductase  
Type I cyclic nucleotide phosphodiesterase  
Type III cyclic AMP phosphodiesterase  
Type V cyclic nucleotide phosphodiesterase  
Transpeptidase  
Thymic lymphocyte antibodies  
Tumour necrosis factor alpha  
Thiamine

5

Uridine monophosphate pyrophosphorylase

Vascular cellular adhesion molecule 1 receptor  
Vasopressin receptors V<sub>1a</sub>, V<sub>1b</sub>, V<sub>2</sub>,  
Viral DNA polymerase  
Vitamin A nuclear receptor  
Vitamin E  
Vitamin K & receptor  
Vitamin B<sub>12</sub> receptor

Vitamin D nuclear receptor  
Voltage-activated  $\text{Ca}^{2+}$  channel, L-type

Below are examples of diseases and the different targets involved in these diseases. It is also presented in outline examples of how new potential drugs for these targets would be screened using the present invention.

**1. Disease Target: Bacterial infections (Inhibition of DNA Polymerase III, P450 inhibition and Multi-drug resistance *S. aureus* growth inhibition)**

The widespread emergence of resistance has significantly limited the efficacy of classical antibiotic therapy for bacterial disease. Fuelled largely by the excessive and often unnecessary use of antibiotics in humans and animals, antibiotic resistance has resulted in increased patient morbidity, mortality and overall cost of health care. Methicillin-resistant *Staphylococcus aureus* (MRSA) is now the most prevalent nosocomial pathogen in the United States, and the enterococci, as opportunistic pathogens, are among the top four causes of nosocomial infection. Indeed, the percentage of enterococcal isolates resistant to essentially every antibiotic, including vancomycin, continues to increase. Thus a premium is placed upon the discovery of inhibitors that function by a novel or at least different mechanism than currently approved antibiotics, as these would be expected to circumvent current bacterial resistance mechanisms.

*S. aureus* is a very important human pathogen and has favorable growth characteristics for use in high-throughput screening. Use of an antibiotic-resistant strain will *a priori* select for hits that have activity against a multi-drug resistant strain.

DNA Polymerase III is a DNA polymerase-exonuclease (Pol-Exo) that is essential for the replicative DNA synthesis of Gram positive organisms. Since DNA Pol III is essential for the replication of Gram positive bacteria, the inhibition of DNA Pol III offers a specific and alternative way to treat antibiotic resistant gram positive bacteria.

Many patients with severe disease may be administered multiple anti-infectives as well as other drugs to treat (non-infectious) underlying disease. In this case, drug classes that are not metabolized via the major P450 liver enzymes are preferable.

Desired therapeutic profile:

- 5     • *Gram positive-specific:* Systemic administration of agents with a very broad spectrum has the undesired effect of creating resistance in the normal host Gastrointestinal flora. Therefore, more disease-specific antibiotics might have an advantage in gaining hospital formulary approval and overall wider acceptance.
- 10    • *Orally-active:* The ideal drug candidate would be orally-active with additional formulations for intravenous use. Multiple dosing is acceptable however anything approaching continuous infusion requires very careful consideration. Improvement or equivalence with dosing regimens of competitive therapies is important.
- 15    • *Safety:* The ideal drug candidate would be microorganism-specific and devoid of significant side-effects and drug interactions within at least 10-fold of  $C_{max}$  in the therapeutic dosing range.

Multiple parameter screens:

- 20     A multiple parameter screen would thus include *S. Aureus* growth inhibition, DNA Polymerase III inhibition and P450 inhibition. A screen could be assembled by, for example, transforming a library of producer strains with GFP reporter systems for a few selected human P450s and for recombinant *Bacillus subtilis* DNA Pol III. The library would then be plated and overlaid with an MRSA strain. An assay where
- 25     the compounds have to cross the producer's cell wall and reach the reporter strain will also select for compounds that have a reasonable solubility profile.

30     Figure 3 exemplifies such a multiple parameter screen where producer cells in zones cleared of MRSA cells and which produce the desired combination of fluorescent colours would be selected.

2. **Disease target: Cancer - Inhibition of solid tumour growth and prevention of metastasis (inhibition of NF- $\kappa$ B, inhibition Cox-2, no inhibition Cox-1)**

Cancer is the second leading cause of death in the US, causing one in every four deaths. Existing treatments for surgically inoperable cancers include chemotherapy and radiation treatments. These are highly toxic because they are non selective or at best only partially selective. There exists a critical need for new therapeutics to inhibit tumor growth and prevent metastasis. A premium is placed upon molecules that prevent metastasis and which work through a selective mechanism so as to avoid or minimize side effects.

Nuclear Factor  $\kappa$ B (NF- $\kappa$ B) is a transcription factor that, by regulating the expression of multiple inflammatory and immune genes, plays a critical role in host defense and several pathogenic processes. Its most common inducible form is composed of the proteins p65 and p50, and usually exists as a molecular complex with one of several inhibitory molecules, the I $\kappa$ Bs, in the cytoplasm. Proteins that are regulated by NF- $\kappa$ B include TNF $\alpha$ , IL-1 $\beta$ , IL-2, IL-6, IL-8, iNOS, COX-2, intercellular adhesion molecule-1 (ICAM-1), vascular-cell adhesion molecule-1 (VCAM-1) and E-selectin (*Cancer J.*, 1998, 4, S92; *Int. J. Biochem. Cell. Biol.*, 1997, 29, (6), 867).

Activation of NF- $\kappa$ B can lead to the synthesis of the inducible form of cyclooxygenase (COX-2). This enzyme has a critical role in the response of tissues to injury or infectious agents and are essential components of the inflammatory response, the ultimate repair of injury, and carcinogenesis. Several population-based studies have detected a 40-50% decrease in relative risk for colorectal cancer in persons who regularly use Aspirin and other NSAIDs. Attempts to determine the molecular basis for these observations found that both human and animal colorectal tumors express high levels of COX-2, whereas the normal intestinal mucosa has low to undetectable COX-2 expression. These findings led to the hypothesis that COX-2 plays a role in colon cancer growth and progression (*Faseb*, 1998, 12, 1063). Since Aspirin also inhibits NF- $\kappa$ B these findings also suggest that inhibiting NF- $\kappa$ B may prevent tumour growth and progression. Another way in which COX-2 seems to be involved in cancerinogenesis is by protecting cells from apoptosis (*J. Nat. Cancer Inst.*, 1998, 90, (11), 802). Therefore, inhibition of NF- $\kappa$ B can help control tumor growth by one further process since it leads to less COX-2 induced protection from apoptosis. Inhibition of NF- $\kappa$ B also leads to an increase in Tumor Necrosis Factor (TNF) which in turn leads to an increase in apoptosis.

Immense effort is being devoted to developing new molecules that are direct inhibitors of the enzymatic activity of COX-2. However, an alternative approach is to find new agents that can prevent expression of the respective genes coding for the activities since there are already examples that inhibition of a single mediator does not eliminate all symptoms of a disease (*Inflamm. Res.*, 1997, 46, 282).

Desired therapeutic profile:

- *Selective NF- $\kappa$ B inhibitor:* There are several drugs that act by partial inhibition of NF- $\kappa$ B but they all produce side effects due to interactions with other targets. Any new NF- $\kappa$ B inhibitor would have to be selective.
- *Selective COX-2 inhibitor with a Cox-2/Cox-1 differential inhibitory activity as low as possible:* Prostanoids that are derived from the COX-1 pathway regulate platelet aggregation via thromboxane A<sub>2</sub>, the function and integrity of gut mucosa, and kidney function via prostaglandin E<sub>2</sub> and prostacyclin. Cox-2 is expressed in various cell types, including monocytes, fibroblasts and synovial cells, in response to inflammatory stimuli. Consequently, COX-1 inhibition by NSAIDs is associated with gastrointestinal and renal toxicity, whereas, COX-2 inhibition limits the formation of pro-inflammatory at the site of the inflammatory response and has anticancer effects.
- *Orally-active:* Given the severity of the medical problem, an orally-active drug would be desired but not essential.
- *Safety:* The ideal candidate would be selective and devoid of significant side-effects and drug interactions. However again, given the severity of many cancers and lack of therapeutic options, there is significant history of compounds that are less-than-ideal in these parameters.

Multiple Parameter Screen:

A multiple parameter screen set up could for example be the double gel encapsulation of a producer species library with 2 different mammalian cell lines. The first gel capsule would contain the producer cell and a mammalian cell reporting

NF- $\kappa$ B and Cox-1 inhibition while the second capsule would contain a second mammalian cell line reporting Cox-2 inhibition. Gel droplets producing the desired fluorescence output would be selected.

5     **3. Disease target: Cancer (survival in the presence of DNA Topoisomerase II  $\alpha$  poisons, no production of DNA double strand breaks and inhibition of human DNA topoisomerase II activity)**

10     Chemotherapy is one of the most common approaches to the treatment of cancer. All chemotherapy drugs interfere with cell growth, and they all have some form of side effects. These vary from the highly undesirable to side effects so severe as to prevent further chemotherapy.

15     An underlying problem of chemotherapy is that cancer cells are not that different from normal undifferentiated or fast growing tissues and therefore, killing a cancer cell tends to kill such cells as well. This side effect effectively limits the dose at which the chemotherapeutic can be applied, and hence limits the efficacy that can be achieved. Consequently, there is a need for the development of novel chemotherapeutic agents to overcome these central problems of cancer  
20     chemotherapy.

25     The most common way to address the above problems of cancer chemotherapy is to look for compounds or delivery systems that increase the specificity for cancer cells. However an alternative approach is to use compounds that protect vulnerable normal tissue against the proposed chemotherapeutic agent. Such protectants should of course not be harmful to the normal cells and either not reach, or not be functional in the cancer cells. A number of protectant approaches are in clinical use to day.

30     Many chemotherapeutic agents, e.g., Doxorubicin and Etoposide have a large part of their toxicity (and hence clinical utility) due to the specific way in which they "poison" the enzyme Topoisomerase II, an enzyme with a crucial role in the elongation and termination stages of DNA replication. Rather than blocking the enzyme specifically, these drugs stabilise an intermediate DNA/enzyme/drug  
35     complex, creating double-stranded breaks in the DNA of treated cells. A second

class of structures act by blocking the Topoisomerase II catalytic cycle at other points in the cycle and do not create double-stranded DNA breaks. These two types of compounds are antagonists to each other since they stabilise different points in the cycle. If one binds, the other cannot. Therefore, inhibitors of Topo II can be used to offset the effects of Topo II poisons.

Two highly homologous isoforms of mammalian topoisomerase II have been identified in tumor cells, topoisomerase II  $\alpha$  (170 kDa) and topoisomerase II  $\beta$  (180 kDa) (Malonne, H. and Atassi, G., *Anti-Cancer Drugs*, 1997, **8**, 811-822). The two isoforms differ in several biochemical and pharmacological properties, such as optimal salt concentration for *in vitro* catalytic activity, thermal stability and sensitivity to teniposide (a non-intercalative DNA topoisomerase II poison). Topoisomerase II  $\alpha$  is the major drug target isoform in mammalian cells (Sehested et al, *Cancer Research*, 1998, **58**, 1460-1468).

The discovery of new inhibitors of DNA topoisomerase II would enable the protection of certain vulnerable tissues against Topo II poisons and hence expand the efficacy of existing chemotherapy drugs and reduce side effects.

#### Desired therapeutic profile:

- *DNA topoisomerase II  $\alpha$  inhibitor:* Any new compound would have to be an inhibitor and not a poison of the enzyme.
- *Reversible inhibition of normal cell growth:* The effects of the drug should only last long enough to off set the effects of the chemotherapeutic agent
- *Orally-active:* Given the severity of the medical problem, an orally-active drug would be desired but probably not essential.
- *Safety:* The ideal candidate would have modest toxicity such that it does not by itself place an additional toxicity burden on the patient.

#### Multiple Parameter Screen:

A preferred example of a multiple parameter screen set-up for cancer chemoprotectant is illustrated in Fig. 4b. In the assay, a producer species library is encapsulated so that on average each capsule has 1 cell and allow to grow for a few generations. These clonal lines are then double encapsulated with a permeabilised yeast that contains a human DNA Topo II  $\alpha$  reporter system. The gel droplet environment contains etoposide (a poison) and a DNA double strand break stain. Gel droplets where the yeast cells in the outer layer have survived and that do not fluoresce or are stained are selected.

**4. Disease target: Diabetes (ligand activation of RXR $\alpha$ , ligand specific activation of RXR-PPAR $\gamma$ , adipocyte differentiation).**

Type 2 diabetes is one of the most common chronic diseases and is associated with co-morbidities, such as obesity, hypertension, hyperlipidemia and cardiovascular disease.

Peroxisome proliferator-activated receptors (PPARs) and retinoid X receptors (RXR) are transcription factors belonging to the family of ligand-inducible nuclear receptors. There are three related but distinct PPARs called PPAR-alpha, PPAR-beta/delta and PPAR-gamma that form heterodimers with RXR. These receptors regulate expression of genes involved in fat and carbohydrate metabolism. RXR is unique among retinoid receptors as it can form homo- or heterodimers with multiple nuclear receptors including PPARs, retinoic acid receptors (RARs), vitamin D receptor, and thyroid hormone receptor.

PPAR $\gamma$ /RXR regulates adipogenesis and insulin sensitivity both when activated by PPAR $\gamma$  ligands and/or RXR ligands. For example, insulin sensitizers, such as the drugs from the thiazolidinedione class (TZDs), exert their antidiabetic effects through a mechanism that involves activation of the gamma isoform of the nuclear receptor of the peroxisome proliferator-activated receptor (PPAR $\gamma$ ).

Activation of RXR $\alpha$  increases activation of PPAR $\gamma$  and insulin sensitivity. Clinical studies show that co-administration of retinoids (LG100268) +TZDs increases insulin sensitivity and glucose uptake by 60%



The retinoid receptors mediate the biological effects of natural and synthetic vitamin A derivatives, such as retinoic acid. RXR ligands interact with many different proteins, including members of the following protein families: RXR, RAR, retinoic acid receptor-related orphan receptor (RZR), cytoplasmic retinoic acid-binding proteins, retinal-binding protein, P-glycoprotein and cytochrome P450. The expression level of each of these proteins is likely to affect the potency and efficacy of retinoids in various cell types.

Rexinoids may have undesirable effects mediated by RXR homodimers or heterodimers partners other than PPAR $\gamma$ . Rexinoids for treating type 2 diabetes should thus be selective for the PPAR $\gamma$ /RXR heterodimer.

Desired therapeutic profile:

- *Selectivity:* RXR agonists should be selective for the PPAR $\gamma$ /RXR heterodimer.
- *Orally-active:* The ideal drug candidate would be orally-active.
- *Safety:* The ideal drug candidate would be devoid of significant side-effects and drug interactions.

Multiple Parameter Screen:

A multiple parameter screen set up could be the gel encapsulation of a producer species library reporting RXR-RXR activation with a mammalian cell line reporting PPAR $\gamma$ -RXR activation as well as P450 inhibition. Gel droplets that indicate PPAR $\gamma$ -RXR activation but not RXR-RXR or P450 inhibition are selected. Figure 5 exemplifies such a system.

***Absorption, Distribution, Metabolism, Excretion & Toxicity (ADMET)***

Major reasons for the failure of lead compounds in development often involve inappropriate kinetics or toxicity, thus there is a strong need to obtain the relevant

information as early as possible in the discovery process in order to spend as little as possible on inadequate compounds. The pharmaceutical and biotech industries are thus currently focusing on transforming the traditionally very low throughput processes of physicochemical, pharmacokinetic and toxicity optimization studies into high throughput selection methods in order to obtain the relevant information as early in the discovery process as possible.

Though the use of evolutionary strategies and cell based systems, the present invention enables the inclusion of ADMET requirements in the lead generation process and thus reduces significantly the production and screening of thousands of compounds that are not drug like.

#### *Solubility*

For drugs to be effective they must be able to reach their targets in effective amounts. In cell free assays the only limitation that exists in this regard is the compound's solubility in the assay buffer. In cell-based assays with intracellular targets, the ability of compounds to diffuse across cell membranes is dependent on their ability to partition into and out of lipid-rich membranes. This process is more efficient when compounds have a certain degree of lipophilicity in addition to being sufficiently water-soluble. If the cell culture medium contains proteins (such as from the presence of fetal calf serum) the degree of binding of the compound to serum proteins influences the freely diffusible fraction of compound and hence the amount available for interaction with the target. The extent of drug binding to serum proteins has a number of important implications in the living organism including transport and distribution.

The present invention uses a host species to produce the compounds. In a preferred embodiment it uses assays external to the producer species. Thus it is an inherent part of the process to evaluate the ability of compounds to diffuse across cell membranes. The presence of medium proteins is also an inherent part of the system.

Another aspect of the invention is the control of the expression of the host's drug resistance pumps. This control allows significant pumping of the compounds

produced in the first rounds of screening, when the solubility of compounds produced is not a key selection criteria. In later rounds of screening the expression of the pumps will be progressively turned off in order for the compounds that reach the disease targets to have to cross the host's cell membrane and thus have a reasonable solubility profile.

### *Absorption*

The preferred route of drug delivery is oral administration. The intestinal membrane permeability is a critical characteristic that determines the extent and rate of drug absorption and ultimately the bioavailability. Other cells which are relevant for drug uptake include epithelial, epidermis, nasal, blood-brain and blood-testis barriers, as well as the kidney, liver, intestinal epithelial and lung cells; which are also routes for uptake of drugs.

Most models of absorption involve the use of cultured, immortalised cells, which are generally intestinal in nature and which give a good correlation with absorption in vivo. Most notable among them are CaCO-2 cells that derive from a human colon carcinoma cell line or a subclone of the Caco-2 cell line, TC7. Other useful cell lines for absorption studies are dog kidney cell line, the Madin-Derby Canine kidney cell line (MDCK) and everted intestinal rings and brush-border membrane vesicles (BBMV). These cell lines are grown in a confluent monolayer and used for permeability measurements which are based on the rate of appearance of test compound in the receiver compartment. The apical (donor) surface of the monolayer contains microvilli and thus retains many characteristics of the intestinal brush border. Furthermore, the apically located efflux pump, P-glycoprotein, the monocarboxylic acid transporter, the dipeptide transporter, the transporter for large neutral amino acids (LNAA) [Inui K-I, Yamamoto M, Saito H. T, *J Pharmacol Exp Ther*, 1992; 261: 195-201; Lu S, Guttendorf RJ, Stewart BH, *Pharm Res*, 1994; 11: S-258.] and metabolic enzymes [Bjorge S, Halehlele KL, Homan R, Rose SE, Turluck DA, Wright DS., *Pharm Res*, 1991; 8: 1441-1443] are all functionally expressed.

Figure 6 shows an example of a multiple parameter screen for absorption and a pharmacological activity. Using a dual culture system and timing the time of cell se-

lection, it is possible to select producer cells that have the desired pharmacological activity and a good absorption profile.

Drugs that inhibit P-glycoprotein can alter the absorption, disposition and elimination of co-administered drugs and can enhance bioavailability or cause unwanted drug-drug interactions. Thus another important aspect of absorption studies is to determine if a compound is a PGP inhibitor by a direct measure of inhibition of PGP-mediated digoxin transport across polarized human PGP cDNA -expressing LLC-PK1 cell monolayers.

In mammals, the ABC transporters, like MDR1 and MRP1, have a key role in the functioning of the blood-brain and blood-testis barriers, as well as the kidney, liver, lung, and intestinal epithelial cells. MDR1 is expressed normally on apical membranes of cells derived from excretory tissues, as well as on the luminal surface of cerebral capillary cells (*Gottesman et al., 1993; Cordon-Cardo et al., 1989*). MDR1 and MRP1 are present in the epithelia of the choroid plexus (CP) and both transporters participate in the blood-CSF permeation barrier (*Rao et al., 1999*). MDR1-Pgp contributes to the drug-permeation barrier in cerebral capillary endothelial cells and takes part in elimination of organic cations and xenobiotics from the central nervous system (CNS) (*Rao et al., 1999; Schinkel et al., 1997*). MRP1 contributes to the basolateral broad-specificity drug-permeation barrier in CP, protects this epithelium from xenobiotics and extrudes organic anions and probably also some hydrophobic compounds from the CSF (*Wijnholds et al., 2000*). Some ABC transporters form and regulate specific membrane channels, while others are involved in the elimination of detoxified drug-conjugates, transport of phospholipids or bile acids, and even the initiation of antiviral immune-reaction or specific self-destruction in various cell types. Moreover, members of the ABC transporter family were shown to provide multidrug resistance in pathogenic bacteria and parasites (e.g. *Plasmodium* and *Leishmania* species), while also allowing multixenobiotic resistance (MXR) in a large variety of organisms living in a chemically polluted environment (*Kurelec et al., 1989; 1992*).

In order to predict the penetration of a compound through different pharmacological barriers, a wide range of ABC transporters-compound interactions are also being

tested, e.g., Pgp/MDR1, MRP1, MRP2, MDR3, MRP3, MRP5, MRP6, MXR (BCRP, ABCG2).

### Metabolism

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A drug, once it enters an organism, can experience a variety of biological fates. Drug metabolizing enzymes, including cytochromes P450, (present at high levels in liver, kidney, gut and other organs), can catalyze the chemical conversion of a particular drug to entities (metabolites) which are more aqueous-soluble and more readily excreted than the parent drug from which they were derived. If a parent drug is inherently metabolically unstable, undesirable pharmacokinetic behavior, such as an inappropriately short duration of action or poor oral bioavailability, can be observed. It is therefore, common practice in the industry to gain knowledge about the metabolic stability of lead candidates in order to identify compounds that may turn out to have poor pharmacokinetic profiles.

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In addition, studies in drug metabolism can address the issue of possible drug-drug interactions, which are closely linked to the safe use of drugs in polytherapies. Most undesirable drug-drug interactions occur when two or more compounds compete for the same drug-metabolizing enzyme. The result is usually altered pharmacokinetics for one or more of the compounds involved, sometimes accounting for compound blood levels which are outside of the therapeutic window. These types of interactions can be foreseen with the assistance of studies of the inhibitory effects of test compounds with specific drug metabolizing enzymes.

25

Various *in vitro* methods are available which are being increasingly incorporated into drug discovery strategies. Among the most popular and widely utilized systems in use today are hepatic microsomes. These preparations retain activity of those enzymes that reside in the smooth endoplasmic reticulum, such as cytochromes P450 (CYP), flavin monooxygenases (FMOs), sulfotransferases, UDP-glycosyl transferases, glutathione transferases and N-acetyl transferases. Isolated hepatocytes appear to retain a broader spectrum of enzymatic activities, including not only reticular systems, but cytosolic and mitochondrial enzymes as well. Liver slices, which like hepatocytes retain a wide array of enzyme activities, are also increasingly used. Furthermore, both hepatocytes and liver slices are capable of assessing of enzyme

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induction *in vitro*. Isolated heterologous human CYP enzymes have been available for several years, being expressed from cDNA in yeast (*Saccharomyces cerevisiae*), bacterial (*Escherichia coli*), and mammalian (B-lymphoblastoid) cell lines [Ohgiya S, Komori M, Fujitani T, Miura T, Shinriki N, Kamataki T., *Biochem Int*, 1989; **18**: 429-438; Winters DK, Cederbaum AI, *Biochim Biophys Acta* 1992; **1156**: 43-49; Crespi CL, Gonzalez FJ, Steimel DT, Turner TR, Gelboin HV, Penman BW, Langenbach R, *Chem Res Toxicol*, 1991; **4**: 566-572]. These systems have been used to ascertain whether a compound is a substrate for a particular CYP isozyme and, if so, what metabolite is generated by that enzyme.

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Assays using recombinant human cytochromes P450, (including CYP2D6 & CYP2C19 that are polymorphically-encoded) as well as assays using isozyme-specific substrate and metabolite combinations in liver microsomal preparations can provide valuable information regarding a test compound's drug-drug interaction potential.

15

In the present invention the generation of small molecules is carried out by host cells that can themselves be transformed with a range of enzymes involved in human metabolism. These minimises the number of false positives generated by compounds that are rapidly metabolised by the human DMEs and also leads to the discovery of compounds that are active after being metabolised and which would otherwise remain undiscovered. (see figure 7).

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In another aspect of the invention the drug metabolising enzymes are included extracellular to the small molecule producer cell in either cell free or cell based assays. When using cell based assays, one preferred approach is the use of hepatocytes.

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In yet another aspect of the invention, the drug metabolising enzyme(s) are associated with reporter systems in order to gain information on enzyme inhibition. Alternatively competition assays for drug-drug interactions can be carried out.

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In specific cases, some of the drug metabolising enzymes are themselves the disease targets since several of these enzymes are known to be associated with several diseases.

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Conceptually, the drug metabolizing enzymes are divided into two groups. Oxidative drug metabolizing enzymes, which include CYP450s and FMOs, catalyze the introduction of an oxygen atom into substrate molecules, generally resulting in hydroxylation or demethylation. The conjugative enzyme families include the UDP-glycosyltransferases (UGTs), glutathione transferases (GSTs), sulfotransferases (SULTs), and N-acetyltransferases (NATs). The conjugative drug metabolizing enzymes catalyze the coupling of endogenous small molecules to xenobiotics that usually results in the formation of soluble compounds that are more readily excreted.

#### 10 Cytochrome P450s

Cytochrome P450 proteins in humans are drug metabolizing enzymes and enzymes that are used to make cholesterol, steroids and other important lipids such as prostacyclins and thromboxane A<sub>2</sub>. These last two are metabolites of arachidonic acid. Mutations in cytochrome P450 genes or deficiencies of the enzymes are responsible for several human diseases. Induction of some P450s is a risk factor in several cancers since these enzymes can convert procarcinogens to carcinogens.

CYP450 enzymes in the liver catalyze the initial step in the biotransformation of xenobiotic compounds, including most drugs. These enzymes are members of a large family of mixed-function oxidases that catalyze the introduction of an oxygen atom into substrate molecules, often resulting in hydroxylated or dealkylated metabolites. The metabolism takes place in two phases. Phase I is chemical modification to add a functional group that can be used to attach a conjugate. The conjugate makes the modified compound more water soluble so it can be excreted in the urine. Many P450s add a hydroxyl group in a Phase I step of drug metabolism. The hydroxyl then serves as the site for further modifications in Phase 2 drug metabolism.

More than fifty CYP450 isozymes are known to exist in humans and they have been classified into 18 families and 43 subfamilies based on amino acid sequence similarities. Proteins from the same family are greater than 40% identical at the amino acid level, while those in the same subfamily are greater than 55% identical (Nelson, D.R. (1999) *Arch. Biochem. Biophys.* 369:1-10). In the standard nomenclature, the family is designated by a number followed by a letter designation for the subfamily, and a second number that identifies the individual member of that subfamily.

- CYP1 drug metabolism (3 subfamilies, 3 genes, 1 pseudogene)
- CYP2 drug and steroid metabolism (13 subfamilies, 16 genes, 16 pseudogenes)
- CYP3 drug metabolism (1 subfamily, 4 genes, 2 pseudogenes)
- CYP4 arachidonic acid or fatty acid metabolism (5 subfamilies, 11 genes, 10 pseudogenes)
- 5 CYP5 Thromboxane A2 synthase (1 subfamily, 1 gene)
- CYP7A bile acid biosynthesis 7-alpha hydroxylase of steroid nucleus (1 subfamily member)
- CYP7B brain specific form of 7-alpha hydroxylase (1 subfamily member)
- 10 CYP8A prostacyclin synthase (1 subfamily member)
- CYP8B bile acid biosynthesis (1 subfamily member)
- CYP11 steroid biosynthesis (2 subfamilies, 3 genes)
- CYP17 steroid biosynthesis (1 subfamily, 1 gene) 17-alpha hydroxylase
- CYP19 steroid biosynthesis (1 subfamily, 1 gene) aromatase forms estrogen
- 15 CYP20 Unknown function (1 subfamily, 1 gene)
- CYP21 steroid biosynthesis (1 subfamily, 1 gene, 1 pseudogene)
- CYP24 vitamin D degradation (1 subfamily, 1 gene)
- CYP26A retinoic acid hydroxylase important in development (1 subfamily member)
- CYP26B probable retinoic acid hydroxylase (1 subfamily member)
- 20 CYP26C probable retinoic acid hydroxylase (1 subfamily member)
- CYP27A bile acid biosynthesis (1 subfamily member)
- CYP27B Vitamin D3 1-alpha hydroxylase activates vitamin D3 (1 subfamily member)
- CYP27C Unknown function (1 subfamily member)
- 25 CYP39 unknown function (1 subfamily member)
- CYP46 cholesterol 24-hydroxylase (1 subfamily member)
- CYP51 cholesterol biosynthesis (1 subfamily, 1 gene, 3 pseudogenes) lanosterol 14-alpha demethylase
- 30 The bulk of drugs are metabolised by a few members of the CYP1, 2, and 3 families and the metabolism occurs primarily in the liver, which contains the highest concentration of CYP450 in the body. However, the importance of extrahepatic metabolism in tissues such as the intestine and lung is also recognized.



The xenobiotic metabolizing P450s are approximately 50 kDa proteins anchored in the endoplasmic reticulum (ER) by a single transmembrane helix in the N-terminus. Cell fractionation using differential centrifugation results in particulate preparations enriched in endoplasmic reticulum, commonly referred to as microsomes. Detailed examination of microsomal fractions from many different individuals has demonstrated significant variability in expression patterns of individual isozymes, however some generalizations are possible (Guengerich, F.P. (1995) *Cytochrome P450: Structure, Mechanism, and Biochemistry* (Second Edition), Chapter 14, edited by Paul R. Ortiz de Montellano, Plenum Press, New York, Shimada, T., *et al.* (1994) *J. Pharmacol. Exp. Ther.* 270:414-23). On average, 70% of the P450s expressed in adult human liver consist of the following isozymes: 1A2, 2A6, 2B6, the 2C subfamily (2C8, 2C9, 2C18, and 2C19), 2D6, 2E1, and the 3A subfamily (3A4 and 3A5).

Another very important aspect of the P450s is that polymorphisms cause significant differences in drug metabolism from population to population and individual to individual. A polymorphism is a difference in DNA sequence found at 1% or higher in a population. These differences in DNA sequence can lead to differences in drug metabolism, so they are important features of P450 genes in humans. CYP2C19 has a polymorphism that changes the enzyme's ability to metabolize mephenytoin (a marker drug). In Caucasians, the polymorphism for the poor metabolizer phenotype is only seen in 3% of the population. However, it is seen in 20% of the Asian population. Because of this difference, it is important to be aware of a person's race when drugs are given that are metabolized differently by different populations. Some drugs that have a narrow range of effective dose before they become toxic might be overdosed in a poor metabolizer. A cytochrome P450 allele website is available from Sweden at <http://www.imm.ki.se/CYPalleles/>

Another aspect of the current invention is the ability to evolve drugs designed for specific populations or even individuals since the drug metabolic aspects are addressed during the drug generation process.

Oxidation of organic molecules by P450s is quite complex (Ortiz de Montellano, P.R. (1995) *Cytochrome P450: Structure, Mechanism, and Biochemistry* (Second Edition), Chapter 8, edited by Paul R. Ortiz de Montellano, Plenum Press, New York), but the overall reaction can be represented simply by Equation 1:



5 An electron from NADPH is transferred via the flavin domain of NADPH-P450 reductase to the heme domain of the CYP450 where the activation of molecular oxygen occurs. Substrates react with one of the oxygen atoms and the other is reduced to water. In some cases, the second electron can come from NADPH via cytochrome *b5* reductase and cytochrome *b5*. During *in vitro* reconstitution experiments, cytochrome *b5* can stimulate metabolism of various substrates by some CYP450  
10 isozymes, notably 3A4, 2E1, and 2C9. However, the mechanism of this stimulation is not clearly understood. Apocytochrome *b5* was shown to be as effective as the holoenzyme in stimulating reconstituted CYP3A4 reactions, so at least in this instance, it does not appear to be playing a direct role in electron transfer (Yamazaki, H., *et al.* (1996) *J. Biol. Chem.* **271**:27438-44). The most widely held hypothesis is  
15 that cytochrome *b5* acts allosterically to enhance the interaction between CYP450 and NADPH-P450 reductase, or it improves substrate binding.

#### *Flavin Monooxygenases (FMOs)*

20 Flavin monooxygenases, like the CYP450 enzymes, are associated with the endoplasmic reticulum and catalyze the oxidation of organic compounds using molecular oxygen and NADPH as the source of electrons for the reduction of one of the oxygen atoms (**Equation 1**). However, they are mechanistically distinct from the CYP450s in that they react with oxygen and NADPH in the absence of substrate to  
25 form a 4 $\alpha$ -hydroperoxy flavin enzyme intermediate. Thus, the FMOs exist in an activated form in the cell, and their interaction with a nucleophilic group such as an amine, thiol, or phosphate, is all that is required for completion of the catalytic cycle (Rettie, A.E. and Fisher, M.B. (1999) in *Handbook of Drug Metabolism*, pp131-147, edited by Thomas F. Woolf, Marcel Dekker, Inc, New York). The capacity to remain  
30 stable while poised in an activated state is a possible explanation for the extremely broad substrate specificity of the FMO isozymes. It has been proposed that essentially all of the energy required for catalysis is captured in the oxygen-activated intermediate, and that alignment or distortion of the substrate molecules is not required (Ziegler, D.M. (1993) *Annu. Rev. Pharmacol. Toxicol.* **33**:179). It follows that  
35 the active site of FMOs is much less sterically defined than for other enzymes.

FMO3 is the most abundant form in human liver and is believed to be the dominant member of this enzyme family in terms of overall drug metabolism (Rettie, A.E. and Fisher, M.B. (1999) in Handbook of Drug Metabolism, pp131-147, edited by Thomas F. Woolf, Marcel Dekker, Inc, New York).

5

*UDP glycosyltransferases (UGTs)*

UDP glycosyltransferases catalyze the glucuronidation of xenobiotics at hydroxyl, carboxyl, amino, imino, and sulfhydryl groups using UDP-glucuronic acid as a donor molecule (**Equation 2**). In general, this generates products that are more hydrophilic and thus more readily excreted in bile or urine.

10

**Equation 2: UDP-glucuronic acid + R → UDP + R-glucuronide**

Although glucuronidation generally is classified as Phase II metabolism – the phase occurring after CYP450 dependent oxidative metabolism – many compounds do not require prior oxidation because they already possess functional groups that can be glucuronidated. Examples of first-pass metabolism catalyzed by UGTs include the UGT2B7- dependent glucuronidation of morphine (Coffman, B., *et al.* (1996) *Drug Metab. Dispos.* 25:1-4) and the glucuronidation of 5-lipoxygenase inhibitors (anti-inflammatories) (Coffman, B., *et al.* (1997) *Drug Metab. Dispos.* 25:1032-8); in the latter case, glucuronidation was demonstrated to be the rate-limiting step for *in vivo* plasma clearance. UGTs are 50-60 kDa integral membrane proteins with the major portion of the protein, including the catalytic domain, located in the lumen of the endoplasmic reticulum and a C-terminal anchoring region of 15-20 amino acids spanning the ER membrane (Radomska-Pandya, A., *et al.* (1999) *Drug Metab. Rev.* 31:817-99.11. Radomska- Pandya, A., *et al.* (1999) *Drug Metab. Rev.* 31:817-99). The aglycone-binding site is believed to be in the N-terminal portion the UGT polypeptide, which is the region of the protein that shows the greatest variability in sequence among UGT isozymes. The UDPGA binding domain is in the highly conserved C-terminal half of the protein. Although not a certainty, it has been hypothesized that association with lipid is required for UGT activity and may influence the access of aglycones to the active site. Two UGT families – UGT1 and UGT2 – have been identified in humans. Although members of these families are less than 50% identical in primary amino acid sequence, they exhibit significant overlap in sub-

25

30

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strate specificity (Radomska- Pandya, A., *et al.* (1999) *Drug Metab. Rev.* **31**:817-99). The members of the UGT1 family that are expressed in human liver, where the majority of xenobiotic metabolism takes place, includes UGT1A1, 1A3, 1A4, 1A6, and 1A9. Although the UGT2 family has not been as extensively studied, it is known that UGT2B4, 2B7, 2B10, 2B11 and 2B15 are expressed in the liver (Radomska- Pandya, A., *et al.* (1999) *Drug Metab. Rev.* **31**:817-99.11. Radomska- Pandya, A., *et al.* (1999) *Drug Metab. Rev.* **31**:817-99). As is the case for other drug metabolizing enzymes such as CYP450s, inter-individual differences in UGT expression levels have been observed and linked to differences in drug responses (Weber, W. (1997) *Pharmacogenetics*, Oxford University Press, New York).

The human UGT1 family includes the major bilirubin metabolizing isoform (UGT1A1) and the isoform that preferentially conjugates planar phenols (UGT1A6). Isoforms in the UGT2 family metabolize a variety of endogenous steroid compounds, as well as xenobiotics. As with the CYP450s, classification of the UGTs based on substrate specificity is somewhat limited since there is a great deal of overlap in the biotransformation capacity for most of the human UGTs.

#### *Glutathione transferases (GSTs)*

Glutathione transferases catalyze the formation of thioether conjugates between glutathione (GSH) and reactive xenobiotics by direct addition (**Equation 3**) or displacement of an electron-withdrawing group (**Equation 4**).

**Equation 3:  $\text{GSH} + \text{R} \rightarrow \text{GS-R}$**

**Equation 4:  $\text{GSH} + \text{R-X} \rightarrow \text{GS-R} + \text{HX}$**

The major biological function of GSTs is believed to provide defense against electrophilic chemical species. The majority of GSTs are cytosolic homodimers composed of approximately 25 kDa subunits from one of four structural classes: Alpha ( $\alpha$ ), Mu ( $\mu$ ), Pi ( $\pi$ ), and Theta ( $\theta$ ). The  $\alpha$  isoform (GST A1-1) is restricted to a few tissues in mammals, including kidney, intestine, lung and liver. The  $\mu$  isoform (GST M1-1) is found in the liver, but relatively few other tissues. In contrast, the  $\pi$  isoform (GST P1-1) is widely distributed throughout the body, although it is notably absent in the liver. Additionally, GST P1-1 is abundant in most types of tumor cells.

### *Sulfotransferases (SULTs)*

Sulfotransferase enzymes catalyze the conjugation of sulfate groups onto a variety of xenobiotic and endogenous substrates that possess acceptor moieties such as hydroxyl and amine groups (Equation 5).

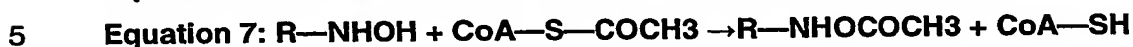


The cofactor 3'-phosphoadenosine 5'-phosphosulfate (PAPS) is required for sulfonation by these enzymes. Although sulfonation generally causes molecules to lose their biological activity, several documented examples indicate that the addition of sulfate can lead to formation of highly reactive metabolic intermediates, such as minoxidil, and reactive electrophilic cations, such as sulfated N-hydroxy 2-acetylaminofluorene (McCall, J., *et al.* (1983) *J. Med. Chem.* **26**:1791-3; Miller, J.A. (1994) *Chem. Bio. Interact.* **92**:329-41). Several sulfotransferase enzymes with different biochemical properties have been characterized in animal and human tissue. Two general classes exist in tissue fractions: the cytosolic enzymes, which are considered important in drug metabolism; and the membrane bound enzymes, which are involved in the sulfonation of glycosaminoglycans and glycoproteins (Weinshilboum, R.M., *et al.* (1997) *FASEB J.* **11**:3-14). The human cytosolic sulfotransferase isozymes function as homodimers of 32-35 kDa subunits. There are currently 10 known sulfotransferases in humans, five of which are known to be expressed in adult liver (SULT1A1, SULT1A2, SULT1A3, SULT1E and SULT2A1). It is expected that other new genes encoding sulfotransferases will be identified. The nomenclature of the different genes, their mRNA and protein products has recently been revised so that "SULT" is the accepted superfamily abbreviation (Raftogianis, R.B., *et al.* (1997) *BBRC* **239**:298-304). Allelic variants of sulfotransferase enzymes do exist and studying their frequency and functional role in drug disposition is a very active area of research.

### N-acetyl Transferases

N-acetyltransferases (NATs) catalyze the biotransformation of aromatic amines or hydrazines to the respective amides and hydrazides (Equation 6) using acetyl co-

enzyme A as a donor. They also will catalyze the O-acetylation of N-hydroxyaromatic amines to acetoxo esters (Equation 7).



There are two known NAT isoforms in humans called NAT1 and NAT2; both are 33 kDa cytosolic proteins found in the liver. NAT1 is also expressed in many other tissues, whereas NAT2 is expressed only in the liver and gut. The two isoforms have  
10 different, but overlapping substrate specificities, with no single substrate appearing to be exclusively acetylated by one isoform or the other. Genetic polymorphisms for N-acetylation are well documented, and may play a role in the susceptibility of certain individuals to bladder and colon cancer, as the NATs are involved in both the activation and detoxification of heterocyclic aromatic amine carcinogens (Weber, W.  
15 (1997) Pharmacogenetics, Oxford University Press, New York).

### Toxicity

One of the main forms of toxicity is hepatotoxicity. Freshly isolated human hepatocytes represent the best in vitro biological system in which to evaluate toxicity. Some  
20 human liver cell lines have been developed that reflect normal human liver metabolism (e.g., ACTIVTox from Amphioxus Inc, and Hep G2 from Cerep). These cell lines can be used in cell proliferation assays that give very good correlation with in vivo results.

25

In the present invention toxicity assessment is an inherent parameter of the screens since the compounds are produced in a host organism. Any compound that is very toxic will not be selected or detected since it will kill the host organism. A more accurate human toxicity assay can be incorporated in the multiple parameter screening  
30 procedure by for example encapsulating hepatocytes with the producer species and disease target(s) and select screening units that activated the disease target(s) in the desired way and have not inhibit hepatocyte growth.

Figure 8 shows a schematic representation of a screening system of the present  
35 invention to evaluate target activity, metabolism by DMEs and cytotoxicity: Using a double gel encapsulation system where in the first droplet are clonal lines of the

producer species transformed with the pharmacological target and DMEs, and in the second droplet are hepatocytes, it is possible to screen for target activity, DME metabolism and hepatotoxicity.

## 5      **Mutagenesis**

The mutagenic ability of a compound is another aspect that has to be addressed in a drug discovery programme. The mutagenicity of a compound can be evaluated by measuring the reverse-mutation rate in microorganisms. For example, there are  
10      several different strains with differing and complementary sensitivities to potential mutagens of the bacterium *Salmonella typhimurium*.

## **MULTIPLE PARAMETER SCREENING FOR OTHER PURPOSES**

### 15      **Screening for herbicides.**

The effect of a compound as a herbicide can be screened with in vitro assays. Primary screens that test the effect as a herbicide include: toxicity, inhibition of photosynthesis, inhibition of central metabolic enzymes.

20

Examples of further screens that can be assayed simultaneously with the first group include: uptake (using hairy root cultures, organ cultures (including shoot cultures), metabolism, lack of toxicity towards other plants (in particular crops) or towards other organisms (animals, humans, insects, fungi).

25

### **Screening for fungicides (agricultural)**

Primary screens are much like the ones used in screening for or evolving herbicides except that fungal cells are used as reporter cells and for uptake.

30

Secondary screens are also more or less of the same type. One particular screen to perform is lack of toxicity towards plants, in particular crop plants.

35

### **Screening for insecticides**

Primary screens include the assays for the function of the compounds as insecticides, i.e. cell based assay for toxicity towards a specific species or group of species of insects, and/or assays for inhibition of specific enzymes in key metabolic functions of insects, or inhibition of reproduction.

5

Secondary screens may include uptake in specific insect organs using e.g. a confluent monolayer of insect cells from the organ in which the insecticide is to be taken up. A further screen includes metabolism by insect metabolic enzymes to test whether the compounds are metabolised or activated by these. Furthermore, it is relevant to screen for lack of toxicity or mutagenicity or teratogenicity towards animals and/or human beings. Another example of a secondary screen is lack of toxicity towards other species of insects.

10

#### **Screening for cosmetics**

15

Primary screens are directed to the function of the compounds as cosmetics.

Secondary screens include the same as for screening for or evolution of pharmaceuticals, i.e. absorption (if relevant), distribution (if relevant), metabolism, excretion (if relevant) and toxicity, mutagenicity and teratogenicity.

20

#### **Screening for flavours**

Primary screens may include automatic assaying for the desired flavour. "Artificial noses" have been developed that can assay for particular flavours or tastes. Artificial noses, or olfactory or vapor-selective detectors can detect low levels of odorants. Examples of such noses are disclosed in e.g. US 6,368,558 and references cited therein. The technique is also known as artificial olfactometry.

25

Secondary screens typically include toxicity, mutagenicity, teratogenicity, metabolism (by e.g. saliva enzymes).

30

Fine chemicals: other examples of multiple parameter screening and evolution include the evolution and screening for fine chemicals, food and feed additives, and catalysts.

35



## SCREENING TECHNIQUES

5 The selection of the positive cells can be achieved by establishing screens where only positive cells survive or by physically selecting positive cells. Survival of positive clones can e.g. be achieved by using assays based on

- a. Survival in the presence of toxic substances
- b. Survival in the presence of other organisms
- 10 c. Use of nutritional reporter genes, e.g., His, or of reporter genes that when giving desired response produce a vital protein, e.g., CDC25

Physical selection of positive cells can be done by the use of:

- a. FACS & intracellular reporter assays (native or engineered)
- 15 b. FACS & Gel encapsulation (single, double or more) & extracellular reporter systems [cell based (native or engineered) or cell free]
- c. Overlay assay & extracellular reporter systems [cell based (native or engineered) or cell free] & picking (manual or automatic)
- d. Single clonal cell line confinement to microtiter plate & extracellular reporter systems [cell based (native or engineered) or cell free] & picking (manual or automatic)
- 20 e. Plating & picking (manual or automatic)

## Flow cytometry

25 In traditional flow cytometry, it is common to analyze very large numbers of cells in a short period of time. Newly developed flow cytometers can analyze and sort up to 100,000 cells per second. In a typical flow cytometer, individual particles pass through an illumination zone and appropriate detectors, gated electronically, measure the magnitude of a pulse representing the extent of light scattered. The magnitude of these pulses are sorted electronically into "bins" or "channels", permitting the display of histograms of the number of cells possessing a certain quantitative property versus the channel number. It was recognized early on that the data accruing from flow cytometric measurements could be analyzed (electronically)

30 rapidly enough that electronic cell-sorting procedures could be used to sort cells with

desired properties into separate "buckets", a procedure usually known as fluorescence-activated cell sorting.

Fluorescence-activated cell sorting has been primarily used in studies of human and animal cell lines and the control of cell culture processes. Fluorophore labeling of cells and measurement of the fluorescence can give quantitative data about specific target molecules or subcellular components and their distribution in the cell population. Flow cytometry can quantitate virtually any cell-associated property or cell organelle for which there is a fluorescent probe (or natural fluorescence).

Cell sorters can handle cell sorting at rates of at least 10,000 cells per second, more preferably at least 50,000 per second, more preferably at least 100,000 per second.

#### **Gel microdroplet encapsulation**

The gel microdroplet technology has had significance in amplifying the signals available in flow cytometric analysis, and in permitting the screening of microbial strains in strain improvement programs for biotechnology. Wittrup et al., (Biotechnol. Bioeng. (1993) 42:351-356) developed a microencapsulation selection method which allows the rapid and quantitative screening of  $>10^6$  yeast cells for enhanced secretion of *Aspergillus awamori* glucoamylase. The method provides a 400-fold single-pass enrichment for high-secretion mutants.

Gel microdroplet or other related technologies can be used in the present invention to localize as well as amplify signals in the high throughput screening of cells. Preferably the screening methods of the present invention are laid out to ensure survival of the producer cell, so that these can be used for further rounds of evolution. However, it is also possible to isolate the expression cassettes and possibly even the artificial chromosomes from the cells and re-insert these into other host cells should this be necessary if the cells are killed by the screen.

Different types of encapsulation strategies and compounds or polymers can be used with the present invention. An encapsulation of particular relevance is the encapsulation in calcium alginate due to its broad applicability. Furthermore, calcium

alginate beads can be made at room temperature and be dissolved by gentle procedures leaving the encapsulated cells alive.

5 A further feature of particular interest is the possibility of coating the beads (or gel microdroplets) with a lipid layer in order to make them impermeable to small molecules. This ensures that small molecules do not leak to the surroundings and that the connection between producer cell and small molecule is not lost during screening and sorting of gel microdroplets.

10 Encapsulation techniques may be employed to localize signal, even in cases where cells are no longer viable. Gel microdrops (GMDs) are small (25 to 200  $\mu\text{m}$  in diameter) particles made with a biocompatible matrix. In cases of viable cells, these microdrops serve as miniaturized petri dishes because cell progeny are retained next to each other, allowing isolation of cells based on clonal growth. The basic  
15 method has a significant degree of automation and high throughput. Cells are encapsulated together with substrates and particles containing a positive clones are sorted. Fluorescent substrate labeled glass beads can also be loaded inside the GMDs. In cases of non-viable cells, GMDs can be employed to ensure localization of signal.

20 Encapsulation can be in beads, high temperature agaroses, gel microdroplets made from agarose, polysaccharide, carbohydrate, alginate, carrageenan, chitosan, cellulose, pectin, dextran, or polyacrylamide, cells, such as ghost red blood cells or macrophages, liposomes, or any other means of encapsulating and localizing  
25 molecules.

Gel encapsulated cells may further be enclosed in a layer essentially non-penetrable to the compounds being-screened. Thereby it is ensured that the compounds remain within the vicinity of the cell and that the physical connection between cell and  
30 compound is not lost. Furthermore leakage from gel droplet to gel droplet is prevented. The non-penetrable material may a lipid material.

Advantageously, cells are encapsulated into gel droplets comprising reporter system(s) prior to sorting by FACS so that the advantages of FACS are combined  
35 with the advantages of gel droplet screening.

The cells and the reporter system(s) may be encapsulated into one layer of gel droplets. The cell may also be encapsulated in one layer of the gel droplet and at least one reporter system is encapsulated in another layer of the same gel droplet. Furthermore, the cell may be encapsulated in one layer of the gel droplet and a first reporter system is encapsulated in another layer of the same gel droplet and at least a second reporter system is encapsulated into yet another layer of the same gel droplet.

For example, methods of preparing liposomes have been described (i.e., U.S. Pat. Nos. 5,653,996, 5,393,530 and 5,651,981), as well as the use of liposomes to encapsulate a variety of molecules U.S. Pat. Nos. 5,595,756, 5,605,703, 5,627,159, 5,652,225, 5,567,433, 4,235,871, 5,227,170). Entrapment of proteins, viruses, bacteria and DNA in erythrocytes during endocytosis has been described, as well (Journal of Applied Biochemistry 4, 418-435 (1982)). Erythrocytes employed as carriers in vitro or in vivo for substances entrapped during hypo-osmotic lysis or dielectric breakdown of the membrane have also been described (reviewed in Ihler, G. M. (1983) J. Pharm. Ther). These techniques are useful in the present invention to encapsulate samples for screening.

An environment suitable for facilitating molecular interactions include, for example, liposomes. Liposomes can be prepared from a variety of lipids including phospholipids, glycolipids, steroids, long-chain alkyl esters; e.g., alkyl phosphates, fatty acid esters; e.g., lecithin, fatty amines and the like. A mixture of fatty material may be employed such a combination of neutral steroid, a charge amphiphile and a phospholipid. Illustrative examples of phospholipids include lecithin, sphingomyelin and dipalmitoylphosphatidylcholine. Representative steroids include cholesterol, cholestanol and lanosterol. Representative charged amphiphilic compounds generally contain from 12-30 carbon atoms. Mono- or dialkyl phosphate esters, or alkyl amines; e.g., dicetyl phosphate, stearyl amine, hexadecyl amine, dilauryl phosphate, and the like.

#### **Other screening systems**

As an alternative to gel droplet screening the selection of positive cells meeting the at least one screening criterion may be performed by means of an overlay assay, said overlay assay comprising reporter system(s), and manual or automatic picking of positive cells.

5

Other systems for screening include the selection of positive cells meeting the at least one screening criterion is performed by means of placing a single clonal cell line in one well of a microtiterplate, said well comprising reporter system(s), and manual or automatic picking of positive cells. This system takes advantage of the many systems developed for automatic handling and analysis of microtiterplates.

10

Cells may also simply be plated on medium and positive cells can be picked either automatically or manually.

15

Cells may also be engineered so that only positive cells are able to survive. These cells may be grown in liquid media or be plated.

#### **Evolution towards multiple parameters**

20

Evolution at its most general is a process, whereby a set of replicating and varying patterns are subjected to a selection process that favours the replication of certain of the variant patterns. The selection process acts on an emergent property (phenotype) that is encoded by the pattern and that varies as a consequence of the underlying variation in the pattern. Over the course of a series of replication events those patterns whose replication is most favoured come to dominate the population.

25

Variation in the patterns occurs as the result of changes in individual patterns or as the result of mixing of individual patterns. Which patterns come to dominate the population is partly a consequence of the selection criteria used and partly a function of the starting population.

30

In living organisms and cells the predominant replicating pattern consists of nucleotide sequences (DNA or – in some virus – RNA) and the criteria on which selection acts is typically mediated through other molecules such as (but not limited

to) proteins, metabolites, and structural macromolecules that are encoded by the nucleotide sequence either directly or indirectly.

5 In genetic algorithms the replicating pattern consists of software defined magnetic states and the variation on which selection acts is typically (but not limited to) the solution of a mathematical algorithm encoded by the magnetic states either directly or indirectly.

10 The ability of a pattern to replicate in a given set of environmental parameters is often referred to as the "fitness" of the pattern. Fitness can be regarded as a mathematical property that replicating patterns "attempt to" optimise. The higher the fitness of any given pattern, the greater the chance it will produce one or more copies of itself, the higher the number of copies it will on average produce, and the lower the chance it will be destroyed prior to replication. As with any mathematical  
15 function the property that is optimised may itself be a complex function of otherwise independent properties. Thus evolution can optimise across more than one criteria. For instance the mating calls of many male insects are optimised to attract females of the same species whilst not attracting predators. The oxygen binding proteins in whale blood are optimised to bind oxygen under one set of conditions and release it  
20 under another set of conditions.

Cells containing genetic material are thus in principle able to evolve by virtue of the variations in the genetic sequence that occur within each cell and the consequences of this variation upon the fitness of the cell in a given set of environmental  
25 parameters and the ability of the cell to pass these genetic sequences on to descendant cells

For the purposes of this invention the term "Fitness Function" shall be taken to mean a mathematical or algebraic equation that calculates a score and where the variable  
30 elements in the equation are output variables that vary between different cells within a *cell population*.

For the purposes of this invention the term "Fitness Score" shall be the score generated by the *fitness function* equation.

35

It shall be understood that any selection process conducted on cells may therefore be conducted according to the following general procedure:

- The fitness function ( $F'$ ) is defined so that it encapsulates the desired phenotype of the cell and mathematically relates this to measurable parameters
- 5 • Each cell or group of cells is measured on one or more parameters
- $F'$  for the cell is calculated according to the measured parameters
- Those cells with the highest  $F'$  scores are removed from the screening locality and allowed to grow. Cells with lower  $F'$  scores are discarded. By the highest  $F'$  score is meant a predetermined percentage of the cells with the highest score,
- 10 • such as the best 1%, 5%, 10 % or 50%, or for very high selection pressures the best 1‰, the best 0.1 ‰, the best 0.01 ‰, the best 0.001 ‰, or the best 0.0001‰.

It is an important teaching of evolution that the criteria on which certain patterns are selected over other patterns is essentially arbitrary – in principle any criterion can be used. That arbitrary, human imposed criteria can be used to generate an evolutionary process in a whole organism is exemplified by the evolution of melanism in moths as a result of industrialisation, the evolution of pedigree dogs with various properties and the evolution of plants with e.g. enhanced levels of commercially valuable oils or more even fruiting times or more attractive scents and colours. The term “breeding” is often used to describe human imposed evolution. Such organisms have increased their fitness according to a given set of human imposed criteria. It shall be obvious from these examples that it is not necessary for the fitness function equation to be explicitly described for the evolution to take place.

It is a further teaching that fitness functions and consequent selection pressures can lead to the organism expressing phenotypes that impose high costs on (and even in some cases kill) the organism. All that is required for this to be the case is that they confer a countervailing benefit that allows the underlying pattern that produces the phenotype to spread. One example is the evolution of the peacock's tail, which whilst making it highly visible and vulnerable to competitors and predators, improves its ability to attract mates and hence replicate. In organisms with diploid or higher ploidy and with sexual reproduction it is even possible for patterns that have a net cost to be maintained in the population at reasonable levels. One example of this is

the maintenance of the sickle cell anaemia mutation in west african human populations. The heterozygote form of the mutation confers a benefit (by making the carrier more resistant to malaria) whilst the homozygote is costly (causing severe anaemia). The positive benefit of the heterozygote results in the underlying pattern being maintained in the population at a relatively high frequency.

It is a further teaching that multiple selection pressures, acting on a population at different locations and times help develop and maintain the variability of replicating patterns in the population.

10

It is a further teaching that if two identical selection pressures are applied to two independent but apparently identical populations then although such populations will each evolve similar phenotypes the genetic patterns that come to dominate the population (and that confer the evolved phenotype) may differ between the populations. An example of different genetic patterns conferring the same phenotype is streptomycin resistance in bacteria.

15

From the above it should be clear that organisms are capable of complex evolutionary responses to a wide range of environmental pressures.

20

The evolution according to the present invention is based on a series or cycle of steps of subjecting a composition of cells to screening and selecting cells exhibiting a predetermined functionality, as shown in Fig. 22. The cycles are repeated until the desired functionality, for example a target specificity and activity is obtained. Another example of general screening strategy is illustrated in Figure 21.

25

In other words, the method of evolution according to the present invention is based on the provision of

1. a suitable set of diverse genetic patterns and also
2. a way of selecting for those genetic patterns within this set that encode for phenotypes that are consistent with these properties and also
3. a way of generating novel genetic patterns from those patterns that were selected in step 2.

30



These steps may then be combined sequentially or in parallel or in some other essentially iterative basis. The present invention sets out how to achieve these requirements.

5 In another aspect of the invention, the methods may be applied to the generation of a pathway derived from sources from multiple natural kingdoms, phyla or orders in the host cell. An example of this would be the generation of a pathway to produce retinoids or other molecules by means of introduction of genes encoding for the production of carotenoid pathways (obtained from fungi, algae and/or plants) as  
10 well as genes encoding for the synthesis of Vitamin A (obtained from mammals) or genes encoding for the production of visual pigments (obtained from insects). By such targeted selection and combination of elements of biochemical pathways across kingdoms or phyla the likelihood of obtaining novel metabolites may be further increased.

15 As previously described a fitness function ( $F'$ ) can be defined that encapsulates the desired phenotype of the cell and mathematically relates this to one or more measured outputs. For example the fitness function may be defined as the multiple of a cell's absorption at two different wavelengths or alternatively it may be defined  
20 as the level of inhibition of one enzyme, divided by the inhibition of another enzyme, or it may be defined as the level of cytotoxic poison that a cell can survive, multiplied by the rate or reproduction of the cell in the absence of the cytotoxic or it may be defined in numerous other ways

25 In each screening round cells are selected that have outputs that correspond to one or more elements of the fitness function. In a preferred embodiment early screening rounds only measure one output whilst later screening rounds measure multiple outputs.

30 Those cells with the highest *fitness scores* in the population are removed from the screening environment for later use and/or analysis. Cells with lower  $F'$  scores may be discarded. By the highest  $F'$  score can be meant a predetermined percentage with the highest score, such as the best 1%, 5%, 10 % or 50%, or for very intense selection or very large cell populations the best 1‰, the best 0.1 ‰, the best 0.01  
35 ‰, the best 0.001 ‰, or the best 0.0001‰ or even the best 0.00001‰. Alternatively

an absolute fitness score can be defined and only those cells that exceed this score are selected. By this approach the percentage of cells that are selected may vary.

5 In a preferred embodiment of this invention the screening and selection processes should be conducted on a repetitive or iterative basis, with each iteration being conducted on a daughter population.

10 For each iteration of the screening step, the fitness score that the cells are categorised upon is defined and the cell population subjected to screening. Over a series of iterations the fitness score is elaborated such that it progressively approaches the desired target value. The fitness score may be elaborated either by being increased or by having additional factors added into the equation that derives the fitness score.

15 The screening criteria are hence progressively optimised towards the desired functionality through the necessary rounds or cycles of screening and selection. The steps are repeated until at least one cell having the desired functionality has been evolved, such as repeated at least twice, such as at least three times, such as at least four times, such as at least five times, such as at least ten times, such as at  
20 least twenty times, such as least fifty times, such as at least one hundred times, such as at least two hundred times

In another embodiment the steps are repeated until at least two cell lines, or at least five cell lines, or at least 10 cell lines, having the desired functionality have been  
25 evolved. In a preferred embodiment at least a part of the cell lines evolved have different genetic patterns or genotypes, in a more preferred embodiment all the cell lines evolved have different genetic patterns or genotypes. By the term cell lines is meant cells originating from cells having met the screening criteria related to the determined screening functionality.

30 The screening criteria (or threshold) for one or more outputs may be increased for each repeat. Increasing criteria may for example be increasing concentration of a chemical, such as a toxin, in growth media for each repeat, or decreasing concentration of one or more nutrition components in the growth media or  
35 decreasing sensitivity or proximity of a reporter construct. Other examples of

increasing criteria may be repetitive changes of temperature, either increasing or decreasing depending on the cell type chosen.

5 The screening criteria may also change character per repeat, such as starting with a concentration of a chemical substance in the growth media, and adding a physical parameter, such as light, in the next repeat, or starting with measuring the activity against one enzyme and adding activity against another enzyme in the next repeat.

10 It is also within the scope of the present invention that screening criteria may be a mixture of the criteria discussed above, ie. increased concentration of a chemical combined with changes of physical parameters, and/or increased concentration of one chemical combined with changed concentration of another.

15 Through this approach and in accordance with the general principles of evolution, over a series of screening and selection cycles host lines that most demonstrate the required characteristics are selected for and come to dominate the population. Over a series of screens the required fitness score is raised or elaborated, favouring those combinations that have led to an improvement in the expression of the desired characteristics.

20 In one embodiment the host cell lines that are a priori believed to be interesting for a given target are selected and the selected lines evolved through a series of screens as set out in Figure 22.

25 In another embodiment the approach is one of an escalator of selection pressure using screens that move from the general / low activity to the specific / high activity with the generation of new genetic patterns between each step.

30 In another embodiment the fitness score is deliberately raised only marginally between selection cycles, such as by no more than 50% or by no more than 25% or by no more than 10% or by no more than 5% or by no more than 1%. Such gradualist selection pressures allow low level responses to be built upon over a series of selection cycles. By selecting marginal improvements in the fitness score such an approach maximises the genetic diversity at each stage in the selection  
35 process.

### Specific strategies for pathway generation

5 In another embodiment the approach is to walk down a specific multi-step metabolite pathway in a manner analogous to playing a slot machine. Once the first step of the pathway is obtained the genetic material for that step is put on "hold" by increasing its relative abundance such that most cells in the cell population contain said genetic material and the other genetic materials are then varied (spun or permed) until the second step is achieved, which is then also put on "hold". This process is repeated until the entire pathway is obtained.

15 In another embodiment the approach is to reverse up a specific multi-step metabolite pathway. Once the last step of the pathway is obtained the genetic material for that step is put on "hold" by increasing its relative abundance such that most cells in the cell population contain said genetic material and the other genetic materials are then varied (spun or permed) until the next but last step is achieved, which is then also put on "hold". This process is repeated until the entire pathway is obtained.

20 Also, a combination of both embodiments may be conducted, so that the pathway is built up from "both ends".

25 In one embodiment of the invention the cells are subjected to the selection criteria under conditions that maximise the number of genes expressed by the cells, including the genes being heterologous to the cells. Alternatively the cells are subjected to the selection criteria under conditions that ensure a certain percentage or set of the genes being heterologous to the cells are expressed

30 It should be understood that the above approaches are general in concept and lend themselves to the construction of many variants, depending on the desired goal.

Furthermore, it should be understood that by using a cell-based system an advantage is that the compounds may be selected also on parameters not being included in the fitness function, in that the system inherently promotes evolution of

compounds exhibiting properties such as not being toxic to the cell, as well as compounds that diffuse rapidly within the cell.

Examples of the approaches to build known or structural class focused pathways are as follows:

5

10

For small to medium sized pathways, i.e. pathways of up to 6-7 steps from metabolites of the host cell, the screening strategy relies on enriching the founder population with relevant genes and on the reasonably high probability of assembling over a series of selection rounds pathways that produce a low level of the desired property.

15

For large pathways (i.e. more than 6-7 steps) the screening strategy mostly involves dividing the pathway into subsets and a) defining screening parameters for each subset in order to build a pathway forwards or b) identifying intermediate metabolites that are feed to the cell population in order to assemble the pathway backwards.

20

For example in the case of retinoid like compounds it is well known that carotenoids are metabolised by specific tissues in specific classes of organisms to produce retinoids. It is thus possible to first evolve a population of cells that produce carotenoids and then mix the genes of this population(s) with those of a population(s) enriched for retinoid genes and in this manner evolve a population that produce retinoid like compounds.

25

Another example is the case of Taxol like compounds, for which the exact biosynthetic pathway is not known but is predicted to be somewhere between 12 and 20 enzymatic steps from yeast metabolites and several of the intermediate compounds have been isolated. It is thus possible to start by feeding a metabolite that is a few steps from Taxol in order to identify a population of cells able to produce Taxol like compounds from this precursor. Once this is achieved, the genes responsible for that small pathway are locked, e.g., integrated in the host's genome, or incorporated in artificial chromosomes at such high levels that statistically they occur in most cells and a second evolution process is started. This time the precursor being fed to the cell population is an earlier metabolite from the Taxol biosynthesis. By repeating this partial evolution a number of times, it is possible to evolve a population of cells that produce Taxol like compounds starting with host metabolites.

35

Finally it should be said it is also possible to produce a class of compounds using a combination of both approaches described, i.e., by starting simultaneous evolution processes that cover the pathway backwards and forwards.

5

### Diverse Genetic Patterns

Given that evolution is a statistical process it is necessary to provide sufficient genetic variation on which selection processes can act. In the present invention, this comprises two elements

10

- Providing a sufficiently large and diverse population
- Controlling the genetic basis of the diversity and how it expresses

15

Selection requires genetic diversity on which to operate. Thus the first requirement of the current invention is to provide a population of cells that embodies a genetic diversity. The term "*genetic diversity*" means that substantially all cells are different, in that they comprise different genes, and/or identical genes under control of different control system, such as different promoters, such that almost each cell initially represents a genotype not represented in any of the other cells. Of course due to cell division a few cells may be substantially identical.

20

The term "Cell Population" shall be taken to mean a population of cells where at least  $10^4$  cells, such as at least  $10^5$  cells, such as at least  $10^6$  cells, such as at least  $10^7$  cells, such as at least  $10^8$  cells, such as at least  $10^9$  cells, such as at least  $10^{10}$  cells, such as at least  $10^{11}$  cells, such as at least  $10^{12}$  cells in the population represent a genotype not represented in any of the other cells.

25

Thus, the principle of the evolution method according to the invention is to obtain a population of cells having a very high genetic diversity.

30

One particular embodiment of this principle is to produce cells with combinations of concatemers comprising cassettes with expressible nucleotide sequences from a number of different expression states, which may be from any number of unrelated or distantly or closely related species, or from species from different kingdoms or

phylae, novel and random combinations of gene products are produced in one single cell.

By inserting novel genes into the host cell, and especially by inserting a high number of novel genes from different expression states, such as from a wide variety of species into a host cell, the gene products from this array of novel genes will interact with the pool of metabolites of the host cell and with each other and modify known metabolites and/or intermediates in novel ways to create novel compounds. Due to the high number of substantially different cells that can be generated using the methods according to the present invention, for example at least  $10^4$  cells, such as at least  $10^5$  cells, such as at least  $10^6$  cells, such as at least  $10^7$  cells, such as at least  $10^8$ , such as at least  $10^9$ , for example at least  $10^{10}$ , such as at least  $10^{12}$ , it is more or less inevitable or at least likely that such large populations will lead to a sub-population having such an interaction. The sub-population having such interaction may comprise at most  $10^{10}$  cells, such as at most  $10^9$  cells, such as at most  $10^8$ , such as at most  $10^7$  cells, such as at most  $10^6$  cells, such as at most  $10^5$  cells, such as at most  $10^4$  cells, such as at most  $10^3$  cells, such as at most  $10^2$  cells or just 10 cells.

#### HOST CELLS

The host cells selected for this purpose are preferably cultivable under standard laboratory conditions using standard culture conditions, such as standard media and protocols. Preferably the host cells comprise a substantially stable cell line, in which the concatemers can be maintained for generations of cell division in a suitable manner. It is also of great advantage that standard techniques for transformation of the host cells are available, especially that methods are known for insertion of artificial chromosomes into the host cells.

It is also of advantage if the host cells are capable of undergoing meiosis to perform sexual recombination. It is also advantageous that meiosis is controllable through external manipulations of the cell culture. One especially advantageous host cell type is one where the cells can be manipulated through external manipulations into different mating types.

The host cell should preferably be conditionally deficient in the abilities to undergo homologous recombination. The host cell should preferably have a codon usage similar to that of the donor organisms. Furthermore, in the case of heterologous genomic DNA, if eukaryotic donor organisms are used, it is preferable that the host cell has the ability to process the donor messenger RNA properly, e.g., splice out introns.

The cells can be bacterial, archaebacteria, or eukaryotic and can constitute a homogeneous cell line or mixed culture. Suitable cells include the bacterial and eukaryotic cell lines commonly used in genetic engineering and protein expression. Suitable mammalian cells include those from, e.g., mouse, rat, hamster, primate, and human, both cell lines and primary cultures.

Preferred prokaryotic host organisms may include but are not limited to *Escherichia coli*, *Bacillus subtilis*, *B. licheniformis*, *B. cereus*, *Streptomyces lividans*, *Streptomyces coelicolor*, *Pseudomonas aeruginosa*, *Myxococcus xanthus*, *Rhodococcus*, *Streptomyces*, *Actinomycetes*, *Corynebacteria*, *Bacillus*, *Pseudomonas*, *Salmonella*, and *Erwinia*. The complete genome sequences of *E. coli* and *Bacillus subtilis* are described by Blattner et al., *Science* 277, 1454-1462 (1997); Kunst et al., *Nature* 390, 249-256 (1997)).

Preferred eukaryotic host organisms are mammals, fish, insects, plants, algae and fungi.

Examples of mammalian cells include those from, e.g., monkey, mouse, rat, hamster, primate, and human, both cell lines and primary cultures. Preferred mammalian host cells include but are not limited to those derived from humans, monkeys and rodents, such as chinese hamster ovary (CHO) cells, NIH/3T3, COS, 293, VERO, HeLa etc (see Kriegler M. in "Gene Transfer and Expression: A Laboratory Manual", New York, Freeman & Co. 1990), and stem cells, including embryonic stem cells and hemopoietic stem cells, zygotes, fibroblasts, lymphocytes, kidney, liver, muscle, and skin cells.

Examples of insect cells include baculo lepidoptera.



Examples of plant cells include maize, rice, wheat, cotton, soybean, and sugarcane. Plant cells such as those derived from *Nicotiana* and *Arabidopsis* are preferred

5 Examples of fungi include penicillium, aspergillus, such as *Aspergillus nidulans*, *podospora*, *neurospora*, such as *Neurospora crassa*, *saccharomyces*, such as *Saccharomyces cerevisiae* (budding yeast), *Schizosaccharomyces*, such as *Schizosaccharomyces pombe* (fission yeast), *Pichia* spp, such as *Pichia pastoris*, and *Hansenula polymorpha* (methylotropic yeasts).

10 The choice of host will depend on a number of factors, depending on the intended use of the engineered host, including pathogenicity, substrate range, environmental hardness, presence of key intermediates, ease of genetic manipulation, and likelihood of promiscuous transfer of genetic information to other organisms. Particularly advantageous hosts are *E. coli*, *lactobacilli*, *Streptomyces*,  
15 *Actinomycetes* and filamentous fungi.

A preferred host cell is yeast due to the following characteristics: it is fast growing, eukaryotic, allows scalable culture capabilities, genetic tools are available, it is metabolically flexible, can have a relatively permeable cell membrane/wall and folds  
20 more heterologous eukaryotic proteins correctly than prokaryotic cells.

Thus, an illustrative and not limiting list of suitable yeast host cells comprise: baker's yeast, *Kluyveromyces marxianus*, *K. lactis*, *Candida utilis*, *Phaffia rhodozyma*, *Saccharomyces boulardii*, *Pichia pastoris*, *Hansenula polymorpha*, *Yarrowia lipolytica*, *Candida paraffinica*, *Schwanniomyces castellii*, *Pichia stipitis*, *Candida shehatae*, *Rhodotorula glutinis*, *Lipomyces lipofer*, *Cryptococcus curvatus*, *Candida* spp. (e.g. *C. palmiophila*), *Yarrowia lipolytica*, *Candida guilliermondii*, *Candida*, *Rhodotorula* spp., *Saccharomycopsis* spp., *Aureobasidium pullulans*, *Candida brumptii*, *Candida hydrocarbofumarica*, *Torulopsis*, *Candida tropicalis*,  
25 *Saccharomyces cerevisiae*, *Rhodotorula rubra*, *Candida flaveri*, *Eremothecium ashbyii*, *Pichia* spp., *Pichia pastoris*, *Schizosaccharomyces pombe* (fission yeast), *Kluyveromyces*, *Hansenula*, *Kloeckera*, *Pichia*, *Pachysolen* spp., or *Torulopsis bombicola*.  
30

In any one host cell it is possible to make all sorts of combinations of expressible nucleotide sequences from all possible sources. Furthermore, it is possible to make combinations of promoters and/or spacers and/or introns and/or terminators in combination with one and the same expressible nucleotide sequence.

5

In a preferred embodiment the cells to be evolved are produced by inserting concatemers comprising the multitude of cassettes into a host cell, in which the concatemers can be maintained and the expressible nucleotide sequences can be expressed in a co-ordinated way. The cassettes comprised in the concatemers may  
10 be cut out from the host cell and re-assembled due to their uniform structure with – preferably – compatible restriction sites between the cassettes.

15

The cells as defined in the present invention are preferably collected into populations for use in the present invention. The composition of cells subjected to evolution is then produced by selecting cells from a population or from several sub-populations. A population of individual cells is a population of expression constructs prepared from randomly assembled or even concatenated expressible nucleotide sequences derived from a plurality of species of donor organisms, in which expressible nucleotide sequences are operably associated with regulatory regions  
20 that drives expression of the expressible nucleotide sequences in an appropriate host cell. The host cells used are capable of producing functional gene products of the donor organisms. Upon expression in the host cell, gene products of the donor organism(s) may interact to form novel biochemical pathways.

25

The population according to this embodiment of the invention may in any one cell comprise a unique and preferably random combination of a high number of expression cassettes being heterologous to the host cells. Through this random combination of expression cassettes novel and unique combinations of gene products are obtained in each cell. Such populations are especially adapted in the  
30 discovery of novel metabolic pathways created through the non-native combinations of gene products.

In a preferred embodiment a population may be defined as a population comprising a collection of individual cells, the cells being denoted

cell<sub>1</sub>, cell<sub>2</sub>, ..., cell<sub>i</sub>, wherein  $i \geq 2$ ,

each cell comprising at least one concatemer of individual oligonucleotide cassettes, each concatemer comprising a nucleotide sequence of the following formula:

5                   [rs<sub>2</sub>-SP-PR-X-TR-SP-rs<sub>1</sub>]<sub>n</sub>

wherein rs<sub>1</sub> and rs<sub>2</sub> together denote a restriction site, SP denotes a spacer of at least two bases, X denotes an expressible nucleotide sequence, PR denotes a promoter, capable of regulating the expression of X in the cell, TR denotes a terminator, and  $n \geq 2$ , and

10           wherein at least one concatemer of cell<sub>1</sub> is different from a concatemer of cell<sub>2</sub>.

In the present context the nucleotide sequence of the formula [rs<sub>2</sub>-SP-PR-X-TR-SP-rs<sub>1</sub>]<sub>n</sub> is also referred to as an expression cassette of the formula [rs<sub>2</sub>-SP-PR-X-TR-SP-rs<sub>1</sub>]<sub>n</sub>.

15

Sub-populations may comprise cells as defined above for populations, but mostly the cells of a sub-population will have at least one trait in common, such as common promoter combinations, genetic material from a common species, a common phenotype or the like.

20

The function of the populations and sub-populations is to act as a source of diversity when obtaining the composition of cells to be evolved. Thus, in one embodiment the composition is a collection of subcompositions, wherein a subcomposition is a collection of individual cells having at least one phenotype in common. In a preferred embodiment the composition comprises at least 2 individual subcompositions, said subcompositions being different, such as at least 5 individual sub-compositions, such as at least 10 individual sub-compositions, wherein each sub-composition comprises at least 10 individual cells, such as at least 50 individual cells, such as at least 100 individual cells, such as at least 10<sup>3</sup> individual cells, such as at least 10<sup>4</sup> individual cells, such as at least 10<sup>5</sup> individual cells, such as at least 10<sup>6</sup> individual cells, such as at least 10<sup>7</sup> individual cells, such as at least 10<sup>8</sup> individual cells, such as at least 10<sup>9</sup> individual cells.

25

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The composition of cells preferably comprises at least 20 individual cells, such as at least 50 individual cells, such as at least 100 individual cells, such as at least 150

35

individual cells, such as at least 200 individual cells, such as at least 250 individual cells, such as at least 500 individual cells, such as at least 750 individual cells, such as at least 1000 individual cells, such as at least  $10^4$  individual cells, such as at least  $10^5$  individual cells, such as at least  $10^6$  individual cells, such as at least  $10^7$  individual cells, such as at least  $10^8$  individual cells, such as at least  $10^9$  individual cells.

In a preferred embodiment at least a majority of the individual cells have a genetic patterns or genotypes, thereby representing a great diversity.

10

The term "founding population" or a "founder populations" shall mean a Cell Population that has not itself been subjected to a selection round, in the present context also referred to as composition of cells. Optionally the expression constructs within the cell population are constructed such that genetic material from species that are known from prior art to produce compounds of a desired structure class, or compounds that have a desired functional effect, or are associated with a desired functional effect independent of knowledge of the compounds, predominate.

15

The term "daughter population" is a cell population having been subjected to at least one selection round. In the present context the daughter population is also referred to as a further modified composition.

20

### **Controlling The Genetic Basis of the Diversity**

25

#### **Sources of Genes**

The natural world contains a significant amount of genetic diversity. Various authorities estimate that there are at least  $10^7$  different species, and that each of these species contains on average at least  $10^4$  genes. Even allowing for the fact that many of these genes are relatively conserved between species this represents a high level of genetic diversity.

30

One approach that can be envisaged for the purposes of the current invention is to source genetic material so as to maximise the taxonomic diversity of the genes obtained.

35

A second is to preferentially source genetic material from organisms that are known or reputed to produce molecules of the structural class or with the functional effects desired or are known or reputed to have a desired functional effect without the molecule being known, or are taxonomically related to any such organism.

A third approach is selection of genes of particular interest.

A fourth approach is to select genes that generally extend the host metabolic pathways.

Optionally these approaches can be combined in any suitable manner.

In one embodiment the heterologous gene is an intact gene comprising all exons and introns, in another embodiment the heterologous gene comprises all exons, but no introns or only some introns of the native gene.

Genes can be sourced through the collection and processing of genetic material of various forms. The expressible nucleotide sequences that can be inserted into the vectors, concatemers, and cells according to this invention encompass any type of nucleotide such as RNA, DNA. Such a nucleotide sequence could be obtained e.g. from cDNA, which by its nature is expressible. But it is also possible to use sequences of genomic DNA, coding for specific genes. Preferably, the expressible nucleotide sequences correspond to full length genes such as substantially full length cDNA, but nucleotide sequences coding for shorter peptides than the original full length clones may also be used. Shorter peptides may still retain the catalytic activity of the native proteins. Thus, a preferred embodiment of this invention is to source and collect messenger transcripts (mRNA) for obtaining cDNA.

Another way to obtain expressible nucleotide sequences is through chemical synthesis of nucleotide sequences coding for known peptide or protein sequences. Thus the expressible DNA sequences does not have to be a naturally occurring sequence, although it may be preferable for practical purposes to primarily use naturally occurring nucleotide sequences. Whether the DNA is single or double stranded will depend on the vector system used.

By the term "Expression state" is meant a state of gene expression (i.e the mRNA transcript population) in a specific cell, tissue, combination of tissues or organism or organisms of a given species as sampled at at any one time. Different expression states are found in different individuals, or in the same individual at different point in time, or in the same individual at different points its life-cycle or in the same individual under differing external conditions. The expression states of given cells or tissues of a given individual will also vary with respect to other cells or tissues of the same individual. Different expression states may also be obtained in the same organ or tissue in any one species or individual by exposing the tissues or organs to different environmental conditions comprising but not limited to changes in developmental stage, age, disease, infection, drought, humidity, salinity, exposure to xenobiotics, physiological effectors, temperature, pressure, pH, light, gaseous environment, chemicals such as toxins.

In the following the invention is described in the order in which the steps of obtaining a transformed host cell containing an evolvable artificial chromosome may be performed, starting with the entry vector.

In most cases the orientation with respect to the promoter of an expressible nucleotide sequence will be such that the coding strand is transcribed into a proper mRNA. It is however conceivable that the sequence may be reversed generating an antisense transcript in order to block expression of a specific gene.

Each cell of the *cell population* is initially produced by combining genes selected from at least one expression state. It is of course also possible from the onset to combine genes from two, three, four or more expression states in one host cell or to combine genes from different organisms in one cell. In some embodiments of the invention it is preferred to combine genes from a large variety of organisms into a single host in a manner so that each cell comprises at least two expressible nucleotide sequences, said sequences being heterologous to the cell, i.e. the sequences are not found in the native cell type.

A wide variety of combinations of expressible nucleotide sequences from all possible sources may occur in the cells. Furthermore, it is possible to make

combinations of promoters and/or spacers and/or introns and/or terminators in combination with one and the same expressible nucleotide sequence.

Thus in any one cell there may preferably be expressible nucleotide sequences from two different expression states. Furthermore, these two different expression states may be from one species or advantageously from two different species. Any one host cell may also comprise expressible nucleotide sequences from at least three species, such as from at least four, five, six, seven, eight, nine or ten species, or from more than 15 species such as from more than 20 species, for example from more than 30, 40 or 50 species, such as from more than 100 different species, for example from more than 300 different species, such as from more than 500 different species, for example from more than 750 different species, thereby obtaining combinations of large numbers of expressible nucleotide sequences from a large number of species. In this way potentially unlimited numbers of combinations of expressible nucleotide sequences can be combined across different expression states. These different expression states may represent at least two different tissues, such as at least two organs, such as at least two species, such as at least two genera. The different species may be from at least two different phylae, such as from at least two different classes, such as from at least two different divisions, more preferably from at least two different sub-kingdoms, such as from at least two different kingdoms. Thus expressible nucleotide sequences may be combined from a eukaryote and a prokaryote into one and the same cell.

According to another embodiment of the invention, the expressible nucleotide sequences may be from one and the same expression state. The products of these sequences may interact with the products of the genes in the host cell and with each other and form new enzyme combinations leading to novel biochemical pathways.

#### Sources of genetic diversity

30

Examples of groups of species and individual species known to produce compounds with structural or functional utility include without limitation

35	Bacteria	Streptomyces,	Micromonospora,	Norcadia,	Actinomadura,	Actinoplanes,
		Streptosporangium,	Microbispora,	Kitasatosporium,	Azobacterium,	Rhizobium,
		Achromobacterium,	Enterobacterium,	Brucella,	Micrococcus,	Lactobacillus, Bacillus

		(B.t. toxins), Clostridium (toxins), Brevibacterium, Pseudomonas, Aerobacter, Vibrio, Halobacterium, Mycoplasma, Cytophaga, Myxococcus
5	Fungi	Amanita muscaria (fly agaric, ibotenic acid, muscimol), Psilocybe (psilocybin) Physarium, Fuligo, Mucor, Phytophthora, Rhizopus, Aspergillus, Penicillium (penicillin), Coprinus, Phanerochaete, Acremonium (Cephalosporin), Trochoderma, Helminthosporium, Fusarium, Alternaria, Myrothecium, Saccharomyces
10	Algae	Digenea simplex (kainic acid, antihelminthic), Laminaria anqustata (laminine, hypotensive)
	Lichens	Usnea fasciata (vulpinicacid, antimicrobial; usnic acid, antitumor)
15	Higher Plants	Artemisia (artemisinin), Coleus (forskolin), Desmodium (K channel agonist), Catharanthus (Vinca alkaloids), Digitalis (cardiac glycosides), Podophyllum (podophyllotoxin), Taxus (taxol), Cephalotaxus (homoharringtonine), Camptotheca (Camptothecin), Camellia sinensis (Tea), Cannabis indica, Cannabis sativa (Hemp), Erythroxylum coca (Coca), Lophophora williamsii (Peyote) Myristica fragrans (Nutmeg), Nicotiana, Papaver somniferum (Opium Poppy), Phalaris arundinacea (Reed canary grass)
20	Protozoa	Ptychodiscus brevis; Dinoflagellates (brevitoxin, cardiovascular)
25	Sponges	Microclona prolifera (ectyonin, antimicrobial) Cryptotethya cryta (D-arabino furanosides)
	Coelenterata	Portuguese Man o War & other jellyfish and medusoid toxins.
30	Corals	Pseudoterogonia species (Pseudoteracins, anti-inflammatory), Erythropodium (erythroides, anti-inflammatory)
	Aschelminths	Nematode secretory compounds
35	Molluscs	Conus toxins, sea slug toxins, cephalopod neurotransmitters, squid inks
	Annelida	Lumbriconereis heteropa (nereistoxin, insecticidal)
	Arachnids	Dolomedes ("fishing spider" venoms)
40	Crustacea	Xenobalanus (skin adhesives)
	Insects	Epilachna (mexican bean beetle alkaloids)



	Spinunculida	Bonellia viridis (bonellin, neuroactive)
	Bryozoans	Bugula neritina (bryostatins, anti cancer)
5	Echinoderms	Crinoid chemistry
	Tunicates	Trididemnum solidum (didemnin, anti-tumor and anti-viral; Ecteinascidia turbinata ecteinascidins, anti-tumor)
10	Vertebrates	Eptatretus stoutii (eptatretin, cardioactive), Trachinus draco (proteinaceous toxins, reduce blood pressure, respiration and reduce heart rate). Dendrobatid frogs (batrachotoxins, pumiliotoxins, histrionicotoxins, and other polyamines); Snake venom toxins; Ornithorhynchus anatinus (duck-billed platypus venom), modified carotenoids, retinoids and steroids; Avians: histrionicotoxins, modified carotenoids,
15		retinoids and steroids

### Controlling Gene Expression - Expression Cassettes

20 Genes primarily give rise to selectable phenotypes through transcription of the gene to RNA and translation of the RNA to protein. Furthermore phenotypes are often the result of interactions between multiple genes and their gene products

25 Thus it is an element of the current invention that the heterologous genes are provided in a format whereby their individual and collective expression (transcription to RNA) can be controlled.

30 It is likely that through the combination of a high number of non-native genes in a host cell combinations of genes or single genes are inserted that are lethal or sub-lethal to the host cell. Through the co-ordinated expression of the genes in the host cell it is possible not only to initiate the expression of any subset of genes but also to repress such expression, e.g. of lethal or sub-lethal genes.

35 Through external regulation of the promoters controlling the expressible nucleotides sequences novel and non-naturally occurring combinations of expressed genes can be obtained. Since these novel and non-natural combinations of gene products are found in one and the same cell, the heterologous gene products may affect the metabolism of the host cell in novel ways and thus cause it to produce novel primary or secondary metabolites and/or known metabolites in novel amounts and/or known

metabolites in novel compartments of the cell or outside the cells. The novel metabolic pathways and/or novel or modified metabolites may be obtained without substantially recombining the introduced genes with a segment in the host genome or an episome of the host cells by as well as without intra- or extra concatemeric recombination.

By having expressible nucleotide sequences under the control of a number of independently inducible or repressible promoters, a large number of different expression states can be created inside one single cell by selectively turning on and off groups of the inserted expressible nucleotide sequences. The number of independently inducible and/or repressible promoters in one cell may vary from 1 to 10, such as 2, 3, 4, 5, 6, 7, 8, or 9, or even up to 15, 20, 25 or above 50 promoters.

In the evolution steps the functionality of the controllable promoters of the cells is used, since due to the controllable promoters it is possible during the screening and selection step to switch promoters on and off, thereby creating a greater diversity of expressed genes.

The term promoter is used with its normal meaning, i.e. a DNA sequence to which RNA polymerase binds and initiates transcription. The promoter determines the polarity of the transcript by specifying which strand will be transcribed.

- Bacterial promoters normally consist of -35 and -10 (relative to the transcriptional start) consensus sequences which are bound by a specific sigma factor and RNA polymerase.
- Eukaryotic promoters are more complex. Most promoters utilized in expression vectors are transcribed by RNA polymerase II. General transcription factors (GTFs) first bind specific sequences near the transcriptional start and then recruit the binding of RNA polymerase II. In addition to these minimal promoter elements, small sequence elements are recognized specifically by modular DNA-binding / trans-activating proteins (e.g. AP-1, SP-1) which regulate the activity of a given promoter.
- Viral promoters may serve the same function as bacterial and eukaryotic promoters. Upon viral infection of their host, viral promoters direct transcription either by using host transcriptional machinery or by supplying virally encoded enzymes to substitute part of the host machinery. Viral

promoters are recognised by the transcriptional machinery of a large number of host organisms and are therefore often used in cloning and expression vectors.

5 Promoters may furthermore comprise regulatory elements, which are DNA sequence elements which act in conjunction with promoters and bind either repressors (e.g., lacO/ LAC Iq repressor system in E. coli) or inducers (e.g., gal1/ GAL4 inducer system in yeast). In either case, transcription is virtually "shut off" until the promoter is derepressed or induced, at which point transcription is "turned-  
10 on". The choice of promoter in the cassette is primarily dependent on the host organism into which the cassette is intended to be inserted. An important requirement to this end is that the promoter should preferably be capable of functioning in the host cell, in which the expressible nucleotide sequence is to be expressed.

15 Preferably the promoter is an externally controllable promoter, such as an inducible promoter and/or a repressible promoter. The promoter may be either controllable (repressible/inducible) by chemicals such as the absence/presence of chemical inducers, e.g. metabolites, substrates, metals, hormones, sugars. The promoter may  
20 likewise be controllable by certain physical parameters such as temperature, pH, redox status, growth stage, developmental stage, or the promoter may be inducible/repressible by a synthetic inducer/repressor such as the gal inducer.

In order to avoid unintentional interference with the gene regulation systems of the  
25 host cell, and in order to improve controllability of the co-ordinated gene expression the promoter is preferably a synthetic promoter. Suitable promoters are described in US 5,798,227, US 5,667,986. Principles for designing suitable synthetic eukaryotic promoters are disclosed in US 5,559,027, US 5,877,018 or US 6,072,050.

30 Synthetic inducible eukaryotic promoters for the regulation of transcription of a gene may achieve improved levels of protein expression and lower basal levels of gene expression. Such promoters preferably contain at least two different classes of regulatory elements, usually by modification of a native promoter containing one of the inducible elements by inserting the other of the inducible elements. For example,  
35 additional metal responsive elements (R:Es) and/or glucocorticoid responsive

elements (GREs) may be provided to native promoters. Additionally, one or more constitutive elements may be functionally disabled to provide the lower basal levels of gene expression.

5 Preferred examples of promoters include but is not limited to those promoters being induced and/or repressed by any factor selected from the group comprising carbohydrates, e.g. galactose; low inorganic phosphase levels; temperature, e.g. low or high temperature shift; metals or metal ions, e.g. copper ions; hormones, e.g. dihydrotestosterone; deoxycorticosterone; heat shock (e.g. 39°C); methanol; redox-  
10 status; growth stage, e.g. developmental stage; synthetic inducers, e.g. gal inducer. Examples of such promoters include ADH 1, PGK 1, GAP 491, TPI, PYK, ENO, PMA 1, PHO5, GAL 1, GAL 2, GAL 10, MET25, ADH2, MEL 1, CUP 1, HSE, AOX, MOX, SV40, CaMV, Opaque-2, GRE, ARE, PGK/ARE hybrid, CYC/GRE hybrid, TPI/ $\alpha$ 2 operator, AOX 1, MOX A.

15 More preferably, however the promoter is selected from hybrid promoters such as PGK/ARE hybrid, CYC/GRE hybrid or from synthetic promoters. Such promoters can be controlled without interfering too much with the regulation of native genes in the expression host.

20 In the following, examples of known yeast promoters that may be used in conjunction with the present invention are shown. The examples are by no way limiting and only serve to indicate to the skilled practitioner how to select or design promoters that are useful according to the present invention.

25 Although numerous transcriptional promoters which are functional in yeasts have been described in the literature, only some of them have proved effective for the production of polypeptides by the recombinant route. There may be mentioned in particular the promoters of the PGK genes (3-phosphoglycerate kinase, TDH genes  
30 encoding GAPDH (Glyceraldehyde phosphate dehydrogenase), TEF1 genes (Elongation factor 1), MF $\alpha$ 1 ( $\alpha$  sex pheromone precursor) which are considered as strong constitutive promoters or alternatively the regulatable promoter CYC1 which is repressed in the presence of glucose or PHO5 which can be regulated by thiamine. However, for reasons which are often unexplained, they do not always allow the  
35 effective expression of the genes which they control. In this context, it is always

advantageous to be able to have new promoters in order to generate new effective host/vector systems. Furthermore, having a choice of effective promoters in a given cell also makes it possible to envisage the production of multiple proteins in this same cell (for example several enzymes of the same metabolic chain) while  
5 avoiding the problems of recombination between homologous sequences.

In general, a promoter region is situated in the 5' region of the genes and comprises all the elements allowing the transcription of a DNA fragment placed under their control, in particular:

- 10 (1) a so-called minimal promoter region comprising the TATA box and the site of initiation of transcription, which determines the position of the site of initiation as well as the basal level of transcription. In *Saccharomyces cerevisiae*, the length of the minimal promoter region is relatively variable. Indeed, the exact location of the TATA box varies from one gene to another and may be situated from -40 to -  
15 120 nucleotides upstream of the site of the initiation (Chen and Struhl, 1985, EMBO J., 4, 3273-3280)
- (2) sequences situated upstream of the TATA box (immediately upstream up to several hundreds of nucleotides) which make it possible to ensure an effective level of transcription either constitutively (relatively constant level of transcription  
20 all along the cell cycle, regardless of the conditions of culture) or in a regulatable manner (activation of transcription in the presence of an activator and/or repression in the presence of a repressor). These sequences, may be of several types: activator, inhibitor, enhancer, inducer, repressor and may respond to cellular factors or varied culture conditions.

25

Examples of such promoters are the ZZA1 and ZZA2 promoters disclosed in US 5,641,661, the EF1- $\alpha$  protein promoter and the ribosomal protein S7 gene promoter disclosed in WO 97/44470,, the COX 4 promoter and two unknown promoters (SEQ ID No: 1 and 2 in the document) disclosed in US 5,952,195. Other useful promoters  
30 include the HSP150 promoter disclosed in WO 98/54339 and the SV40 and RSV promoters disclosed in US 4,870,013 as well as the PyK and GAPDH promoters disclosed in EP 0 329 203 A1.

More preferably the invention employs the use of synthetic promoters. Synthetic  
35 promoters are often constructed by combining the minimal promoter region of one

gene with the upstream regulating sequences of another gene. Enhanced promoter control may be obtained by modifying specific sequences in the upstream regulating sequences, e.g. through substitution or deletion or through inserting multiple copies of specific regulating sequences. One advantage of using synthetic promoters is that they can be controlled without interfering too much with the native promoters of the host cell.

One such synthetic yeast promoter comprises promoters or promoter elements of two different yeast-derived genes, yeast killer toxin leader peptide, and amino terminus of IL-1 $\beta$  (WO 98/54339).

Another example of a yeast synthetic promoter is disclosed in US 5,436,136 (Hinnen et al), which concerns a yeast hybrid promoter including a 5' upstream promoter element comprising upstream activation site(s) of the yeast PHO5 gene and a 3' downstream promoter element of the yeast GAPDH gene starting at nucleotide -300 to -180 and ending at nucleotide -1 of the GAPDH gene.

Another example of a yeast synthetic promoter is disclosed in US 5,089,398 (Rosenberg et al). This disclosure describes a promoter with the general formula - (P.R.(2)-P.R.(1))- wherein:

P.R.(1) is the promoter region proximal to the coding sequence and having the transcription initiation site, the RNA polymerase binding site, and including the TATA box, the CAAT sequence, as well as translational regulatory signals, e.g., capping sequence, as appropriate;

P.R.(2) is the promoter region joined to the 5'-end of P.R.(1) associated with enhancing the efficiency of transcription of the RNA polymerase binding region;

In US 4,945,046 (Horii et al) discloses a further example of how to design a synthetic yeast promoter. This specific promoter comprises promoter elements derived both from yeast and from a mammal. The hybrid promoter consists essentially of *Saccharomyces cerevisiae* PHO5 or GAP-DH promoter from which the upstream activation site (UAS) has been deleted and replaced by the early enhancer region derived from SV40 virus.

Co-ordinated expression of gene subsets can also be utilised to identify which heterologous genes are responsible for the production of a given phenotype.

In the following the sequence of steps to be taken when starting with the isolation of mRNA until insertion to an entry vector for providing the cells according to the invention is described. In short the sequence may include the following steps

- i) isolating mRNA from an expression state,
- ii) obtaining substantially full length cDNA clones corresponding to the mRNA sequences,
- 10      iii) inserting the substantially full length cDNA clones into a cloning site in a cassette in a primary vector, said cassette being of the general formula in 5'→3' direction:  
[RS1-RS2-SP-PR-CS-TR-SP-RS2'-RS1']  
wherein CS denotes a cloning site.

15

#### **Expression cassettes**

The expression cassettes according to the present invention are preferably arranged as a cassette of nucleotides in a highly ordered sequence, the cassette having the general formula in 5'→3' direction:

20

[RS1-RS2-SP-PR-CS-TR-SP-RS2'-RS1']

wherein RS1 and RS1' denote restriction sites, RS2 and RS2' denote restriction sites different from RS1 and RS1', SP denotes a spacer sequence of at least two nucleotides, PR denotes a promoter, CS denotes a cloning site, and TR denotes a terminator, all of them being as discussed elsewhere in this specification.

25

It is an advantage to have two different restriction sites flanking both sides of the expression construct. By treating the primary vectors with restriction enzymes cleaving both restriction sites, the expression construct and the primary vector will be left with two non-compatible ends. This facilitates a concatenation process, since the empty vectors do not participate in the concatenation of expression constructs.

30

In principle, any restriction site, for which a restriction enzyme is known can be used. These include the restriction enzymes generally known and used in the field of

molecular biology such as those described in Sambrook, Fritsch, Maniatis, "A laboratory Manual", 2<sup>nd</sup> edition. Cold Spring Harbor Laboratory Press, 1989.

5 The restriction site recognition sequences preferably are of a substantial length, so that the likelihood of occurrence of an identical restriction site within the cassette is minimised. Thus the first restriction site may comprise at least 6 bases, but more preferably the recognition sequence comprises at least 7 or 8 bases. Restriction sites having 7 or more non N bases in the recognition sequence are generally known as "rare restriction sites" (see example 13). However, the recognition  
10 sequence may also be at least 10 bases, such as at least 15 bases, for example at least 16 bases, such as at least 17 bases, for example at least 18 bases, such as at least 18 bases, for example at least 19 bases, for example at least 20 bases, such as at least 21 bases, for example at least 22 bases, such as at least 23 bases, for example at least 25 bases, such as at least 30 bases, for example at least 35 bases,  
15 such as at least 40 bases, for example at least 45 bases, such as at least 50 bases.

Preferably the first restriction site RS1 and RS1' is recognised by a restriction enzyme generating blunt ends of the double stranded nucleotide sequences. By generating blunt ends at this site, the risk that the vector participates in a  
20 subsequent concatenation is greatly reduced. The first restriction site may also give rise to sticky ends, but these are then preferably non-compatible to the sticky ends resulting from the second restriction site, RS2 and RS2'.

According to a preferred embodiment of the invention, the second restriction site, RS2 and RS2' comprises a rare restriction site. Thus, the longer the recognition  
25 sequence of the rare restriction site the more rare it is and the less likely is it that the restriction enzyme recognising it will cleave the nucleotide sequence at other – undesired – positions.

30 The rare restriction site may furthermore serve as a PCR priming site. Thereby it is possible to copy the cassettes via PCR techniques and thus indirectly "excise" the cassettes from a vector.

Single-stranded compatible ends may be created by digestion with restriction en-  
35 zymes. For concatenation a preferred enzyme for excising the cassettes would be a



5 rare cutter, i.e. an enzyme that recognises a sequence of 7 or more nucleotides. Examples of enzymes that cut very rarely are the meganucleases, many of which are intron encoded, like e.g. I-Ceu I, I-Sce I, I-Ppo I, and PI-Psp I (see example 13d for more). Other preferred enzymes recognize a sequence of 8 nucleotides like e.g. 5 Asc I, AsiS I, CciN I, CspB I, Fse I, MchA I, Not I, Pac I, Sbf I, Sda I, Sgf I, SgrA I, Sse232 I, and Sse8387 I, all of which create single stranded, palindromic compatible ends.

10 Other preferred rare cutters, which may also be used to control orientation of individual cassettes in the concatemer are enzymes that recognize non-palindromic sequences like e.g. Aar I, Sap I, Sfi I, Sdi I, and Vpa (see example 13c for more).

15 Alternatively, cassettes can be prepared by the addition of restriction sites to the ends, e.g. by PCR or ligation to linkers (short synthetic dsDNA molecules). Restriction enzymes are continuously being isolated and characterised and it is anticipated that many of such novel enzymes can be used to generate single-stranded compatible ends according to the present invention.

20 It is conceivable that single stranded compatible ends can be made by cleaving the vector with synthetic cutters. Thus, a reactive chemical group that will normally be able to cleave DNA unspecifically can cut at specific positions when coupled to another molecule that recognises and binds to specific sequences. Examples of molecules that recognise specific dsDNA sequences are DNA, PNA, LNA, phosphothioates, peptides, and amides. See e.g. Armitage, B.(1998) Chem. Rev. 25 98: 1171-1200, who describes photocleavage using e.g. anthraquinone and UV light; Dervan P.B. & Bürlı R.W. (1999) Curr. Opin. Chem. Biol. 3: 688-93 describes the specific binding of polyamides to DNA; Nielsen, P.E. (2001) Curr. Opin. Biotechnol. 12: 16-20 describes the specific binding of PNA to DNA, and Chemical Reviews special thematic issue: RNA/DNA Cleavage (1998) vol. 98 (3) Bashkin J.K. 30 (ed.) ACS publications, describes several examples of chemical DNA cleavers.

Single-stranded compatible ends may also be created e.g. by using PCR primers including dUTP and then treating the PCR product with Uracil-DNA glycosylase (Ref: US 5,035,996) to degrade part of the primer. Alternatively, compatible ends

can be created by tailing both the vector and insert with complimentary nucleotides using Terminal Transferase (Chang, LMS, Bollum TJ (1971) J Biol Chem 246:909).

5 The spacer sequence located between the RS2 and the PR sequence is preferably a non-transcribed spacer sequence. The purpose of the spacer sequence(s) is to minimise recombination between different concatemers present in the same cell or between cassettes present in the same concatemer, but it may also serve the purpose of making the nucleotide sequences in the cassettes more "host" like. A further purpose of the spacer sequence is to reduce the occurrence of hairpin formation  
10 between adjacent palindromic sequences, which may occur when cassettes are assembled head to head or tail to tail. Spacer sequences may also be convenient for introducing short conserved nucleotide sequences that may serve e.g. as PCR primer sites or as target for hybridization to e.g. nucleic acid or PNA or LNA probes allowing affinity purification of cassettes.

15

The cassette may also optionally comprise another spacer sequence of at least two nucleotides between TR and RS2. When cassettes are cut out from a vector and concatenated into concatemers of cassettes, the spacer sequences together ensure that there is a certain distance between two successive identical promoter or  
20 terminator sequences. This distance may comprise at least 50 bases, such as at least 60 bases, for example at least 75 bases, such as at least 100 bases, for example at least 150 bases, such as at least 200 bases, for example at least 250 bases, such as at least 300 bases, for example at least 400 bases, for example at least 500 bases, such as at least 750 bases, for example at least 1000 bases, such  
25 as at least 1100 bases, for example at least 1200 bases, such as at least 1300 bases, for example at least 1400 bases, such as at least 1500 bases, for example at least 1600 bases, such as at least 1700 bases, for example at least 1800 bases, such as at least 1900 bases, for example at least 2000 bases, such as at least 2100 bases, for example at least 2200 bases, such as at least 2300 bases, for example at  
30 least 2400 bases, such as at least 2500 bases, for example at least 2600 bases, such as at least 2700 bases, for example at least 2800 bases, such as at least 2900 bases, for example at least 3000 bases, such as at least 3200 bases, for example at least 3500 bases, such as at least 3800 bases, for example at least 4000 bases, such as at least 4500 bases, for example at least 5000 bases, such as at least 6000  
35 bases.

The number of the nucleotides between the spacer located 5' to the PR sequence and the one located 3' to the TR sequence may be any. However, it may be advantageous to ensure that at least one of the spacer sequences comprises  
5 between 100 and 2500 bases, preferably between 200 and 2300 bases, more preferably between 300 and 2100 bases, such as between 400 and 1900 bases, more preferably between 500 and 1700 bases, such as between 600 and 1500 bases, more preferably between 700 and 1400 bases.

10 If the intended host cell is yeast, the spacers present in a concatemer should preferably comprise a combination of a few ARSes with varying lambda phage DNA fragments.

Preferred examples of spacer sequences include but are not limited to: Lambda  
15 phage DNA, prokaryotic genomic DNA such as E. coli genomic DNA, ARSes.

The cloning site in the cassette in the primary vector should be designed so that any nucleotide sequence can be cloned into it.

20 The cloning site in the cassette preferably allows directional cloning. Hereby is ensured that transcription in a host cell is performed from the coding strand in the intended direction and that the translated peptide is identical to the peptide for which the original nucleotide sequence codes.

25 However according to some embodiments it may be advantageous to insert the sequence in opposite direction. According to these embodiments, so-called antisense constructs may be inserted which prevent functional expression of specific genes involved in specific pathways. Thereby it may become possible to divert metabolic intermediates from a prevalent pathway to another less dominant  
30 pathway.

The cloning site in the cassette may comprise multiple cloning sites, generally known as MCS or polylinker sites, which is a synthetic DNA sequence encoding a series of restriction endonuclease recognition sites. These sites are engineered for

convenient cloning of DNA into a vector at a specific position and for directional cloning of the insert.

Cloning of cDNA does not have to involve the use of restriction enzymes. Other alternative systems include but are not limited to:

- Creator™ Cre-loxP system from Clontech, which uses recombination and loxP sites
- use of Lambda attachment sites (att-λ), such as the Gateway™ system from Life Technologies.

Both of these systems are directional.

The role of the terminator sequence is to limit transcription to the length of the coding sequence. An optimal terminator sequence is thus one, which is capable of performing this act in the host cell.

In prokaryotes, sequences known as transcriptional terminators signal the RNA polymerase to release the DNA template and stop transcription of the nascent RNA.

In eukaryotes, RNA molecules are transcribed well beyond the end of the mature mRNA molecule. New transcripts are enzymatically cleaved and modified by the addition of a long sequence of adenylic acid residues known as the poly-A tail. A polyadenylation consensus sequence is located about 10 to 30 bases upstream from the actual cleavage site.

Preferred examples of yeast derived terminator sequences include, but are not limited to: ADN1, CYC1, GPD, ADH1 alcohol dehydrogenase.

Depending on the nature of the host cell, it may be advantageous that at least one cassette comprises an intron between the promoter and the expressible nucleotide sequence, more preferable that substantially all cassettes comprise an intron between the promoter and the expressible nucleotide sequence. The choice of intron sequence depends on requirements of the host cell.

Thus, optionally the cassette in the vector comprises an intron sequence, which may be located 5' or 3' to the expressible nucleotide sequence. The design and layout of

introns is well known in the art. The choice of intron design largely depends on the intended host cell, in which the expressible nucleotide sequence is eventually to be expressed. The effects of having intron sequence in the expression cassettes are those generally associated with intron sequences.

5.

Examples of yeast introns can be found in the literature and in specific databases such as Ares Lab Yeast Intron Database (Version 2.1) as updated on 15 April 2000. Earlier versions of the database as well as extracts of the database have been published in: "Genome-wide bioinformatic and molecular analysis of introns in  
10 *Saccharomyces cerevisiae*." by Spingola M, Grate L, Haussler D, Ares M Jr. (RNA 1999 Feb;5(2):221-34) and "Test of intron predictions reveals novel splice sites, alternatively spliced mRNAs and new introns in meiotically regulated genes of yeast." by Davis CA, Grate L, Spingola M, Ares M Jr, (Nucleic Acids Res 2000 Apr 15;28(8):1700-6).

15

#### **Primary vectors (entry vectors)**

By the term entry vector is meant a vector for storing and amplifying cDNA or other expressible nucleotide sequences using the cassettes according to the present  
20 invention. The entry vectors or primary vectors are preferably able to propagate in *E. coli* or any other suitable standard host cell. It should preferably be amplifiable and amenable to standard normalisation and enrichment procedures.

25

The entry vector may be of any type of DNA that has the basic requirements of a) being able to replicate itself in at least one suitable host organism and b) allows insertion of foreign DNA which is then replicated together with the vector and c) preferably allows selection of vector molecules that contain insertions of said foreign DNA. In a preferred embodiment the vector is able to replicate in standard hosts like yeasts, bacteria and it should preferably have a high copy number per host cell. It is  
30 also preferred that the vector in addition to a host specific origin of replication, contains an origin of replication for a single stranded virus, such as e.g. the f1 origin for filamentous phages. This will allow the production of single stranded nucleic acid which may be useful for normalisation and enrichment procedures of cloned sequences. A vast number of cloning vectors have been described which are  
35 commonly used and references may be given to e.g. Sambrook, J; Fritsch, E.F; and

Maniatis T. (1989) Molecular Cloning: A laboratory manual. Cold Spring Harbour Laboratory Press, USA, Netherlands Culture Collection of Bacteria ([www.cbs.knaw.nl/NCCB/collection.htm](http://www.cbs.knaw.nl/NCCB/collection.htm)) or Department of Microbial Genetics, National Institute of Genetics, Yata 1111 Mishima Shizuoka 411-8540, Japan ([www.shigen.nig.ac.jp/cvector/cvector.html](http://www.shigen.nig.ac.jp/cvector/cvector.html)). A few type-examples that are the parents of many popular derivatives are M13mp10, pUC18, Lambda gt 10, and pYAC4. Examples of primary vectors include but are not limited to M13K07, pBR322, pUC18, pUC19, pUC118, pUC119, pSP64, pSP65, pGEM-3, pGEM-3Z, pGEM-3Zf(-), pGEM-4, pGEM-4Z,  $\pi$ AN13, pBluescript II, CHARON 4A,  $\lambda^+$ , CHARON 21A, CHARON 32, CHARON 33, CHARON 34, CHARON 35, CHARON 40, EMBL3A,  $\lambda$ 2001,  $\lambda$ DASH,  $\lambda$ FIX,  $\lambda$ gt10,  $\lambda$ gt11,  $\lambda$ gt18,  $\lambda$ gt20,  $\lambda$ gt22,  $\lambda$ ORF8,  $\lambda$ ZAP/R, pJB8, c2RB, pcos1EMBL

Methods for cloning of cDNA or genomic DNA into a vector are well known in the art. Reference may be given to J. Sambrook, E.F. Fritsch, T. Maniatis: Molecular Cloning, A Laboratory Manual (2<sup>nd</sup> edition, Cold Spring Harbor Laboratory Press, 1989).

One example of a circular model entry vector is described in Figure 11. The vector, EVE contains the expression cassette, R1-R2-Spacer-Promoter-Multi Cloning Site-Terminator-Spacer-R2-R1. The vector furthermore contains a gene for ampicillin resistance, AmpR, and an origin of replication for E.coli, ColE1.

The entry vectors EVE4, EVE5, and EVE8 shown in Figures 12, 13 and 14. These all contain SrfI as R1 and AscI as R2. Both of these sites are palindromic and are regarded as rare restriction sites having 8 bases in the recognition sequence. The vectors furthermore contain the AmpR ampicillin resistance gene, and the ColE1 origin or replication for E.coli as well as f1, which is an origin of replication for filamentous phages, such as M13. EVE4 (Fig. 12) contains the MET25 promoter and the ADH1 terminator. Spacer 1 and spacer 2 are short sequences deriving from the multiple cloning site, MCS. EVE5 (Fig. 13) contains the CUP1 promoter and the ADH1 terminator. EVE8 (Fig. 14) contains the CUP1 promoter and the ADH1 terminator. The spacers of EVE8 are a 550-bp lambda phage DNA (spacer 3) and an ARS sequence from yeast (spacer 4).

### Nucleotide library (entry library)

A schematic illustration of the steps leading from expression steps to a nucleotide library are illustrated in figure 9:

5

Methods as well as suitable vectors and host cells for constructing and maintaining a library of nucleotide sequences in a cell are well known in the art. The primary requirement for the library is that it should be possible to store and amplify in it a number of primary vectors (constructs) according to this invention, the vectors (constructs) comprising expressible nucleotide sequences from at least one expression state and wherein at least two vectors (constructs) are different.

10

One specific example of such a library is the well known and widely employed cDNA libraries. The advantage of the cDNA library is mainly that it contains only DNA sequences corresponding to transcribed messenger RNA in a cell. Suitable methods are also present to purify the isolated mRNA or the synthesised cDNA so that only substantially full-length cDNA is cloned into the library.

15

Methods for optimisation of the process to yield substantially full length cDNA may comprise size selection, e.g. electrophoresis, chromatography, precipitation or may comprise ways of increasing the likelihood of getting full length cDNAs, e.g. the SMART™ method (Clontech) or the CapTrap™ method (Stratagene).

20

Preferably the method for making the nucleotide library comprises obtaining a substantially full length cDNA population comprising a normalised representation of cDNA species. More preferably a substantially full length cDNA population comprises a normalised representation of cDNA species characteristic of a given expression state.

25

Normalisation reduces the redundancy of clones representing abundant mRNA species and increases the relative representation of clones from rare mRNA species.

30

Methods for normalisation of cDNA libraries are well known in the art. Reference may be given to suitable protocols for normalisation such as those described in US

35

5,763,239 (DIVERSA) and WO 95/08647 and WO 95/11986. and Bonaldo, Lennon, Soares, Genome Research 1996, 6:791-806; Ali, Holloway, Taylor, Plant Mol Biol Reporter, 2000, 18:123-132.

- 5 Enrichment methods are used to isolate clones representing mRNA which are characteristic of a particular expression state. A number of variations of the method broadly termed as subtractive hybridisation are known in the art. Reference may be given to Sive, John, Nucleic Acid Res, 1988, 16:10937; Diatchenko, Lau, Campbell et al, PNAS, 1996, 93:6025-6030; Caminci, Shibata, Hayatsu, Genome Res, 2000, 10:1617-30, Bonaldo, Lennon, Soares, Genome Research 1996, 6:791-806; Ali, Holloway, Taylor, Plant Mol Biol Reporter, 2000, 18:123-132. For example, enrichment may be achieved by doing additional rounds of hybridization similar to normalization procedures, using e.g. cDNA from a library of abundant clones or simply a library representing the uninduced state as a driver against a tester library from the induced state. Alternatively mRNA or PCR amplified cDNA derived from the expression state of choice can be used to subtract common sequences from a tester library. The choice of driver and tester population will depend on the nature of target expressible nucleotide sequences in each particular experiment.
- 20 Finally, enrichment may be achieved by subtractive hybridisation followed by colony picking.

- 25 In the library an expressible nucleotide sequence coding for one peptide is preferably found in different but similar vectors under the control of different promoters. Preferably the library comprises at least three primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of three different promoters. More preferably the library comprises at least four primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of four different promoters. More preferably the library comprises at least five primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of five different promoters, such as comprises at least six primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of six different promoters, for example comprises at least seven primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of seven different promoters, for example comprises at
- 35



least eight primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of eight different promoters, such as comprises at least nine primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of nine different promoters, for example comprises at least ten primary vectors with an expressible nucleotide sequence coding for the same peptide under the control of ten different promoters.

The expressible nucleotide sequence coding for the same peptide preferably comprises essentially the same nucleotide sequence, more preferably the same nucleotide sequence.

By having a library with what may be termed one gene under the control of a number of different promoters in different vectors, it is possible to construct from the nucleotide library an array of combinations of genes and promoters. Preferably, one library comprises a complete or substantially complete combination such as a two dimensional array of genes and promoters, wherein substantially all genes are found under the control of substantially all of a selected number of promoters.

According to another embodiment of the invention the nucleotide library comprises combinations of expressible nucleotide sequences combined in different vectors with different spacer sequences and/or different intron sequences. Thus any one expressible nucleotide sequence may be combined in a two, three, four or five dimensional array with different promoters and/or different spacers and/or different introns and/or different terminators. The two, three, four or five dimensional array may be complete or incomplete, since not all combinations will have to be present.

The library may suitably be maintained in a host cell comprising prokaryotic cells or eukaryotic cells. Preferred prokaryotic host organisms may include but are not limited to *Escherichia coli*, *Bacillus subtilis*, *Streptomyces lividans*, *Streptomyces coelicolor*, *Pseudomonas aeruginosa*, *Myxococcus xanthus*.

Yeast species such as *Saccharomyces cerevisiae* (budding yeast), *Schizosaccharomyces pombe* (fission yeast), *Pichia pastoris*, and *Hansenula polymorpha* (methylotropic yeasts) may also be used. Filamentous ascomycetes, such as *Neurospora crassa* and *Aspergillus nidulans* may also be used. Plant cells

such as those derived from *Nicotiana* and *Arabidopsis* are preferred. Preferred mammalian host cells include but are not limited to those derived from humans, monkeys and rodents, such as chinese hamster ovary (CHO) cells, NIH/3T3, COS, 293, VERO, HeLa etc (see Kriegler M. in "Gene Transfer and Expression: A Laboratory Manual", New York, Freeman & Co. 1990).

### Concatemers

For the purposes of providing a method for assembling multiple expression cassettes ("cassettes") into a single host cell, and allowing their facile remixing between cells, the expression cassettes are assembled into concatemers.

A concatemer is a series of linked units. The concatemers according to the invention may comprise a selection of expressible nucleotide sequences from just one expression state and can thus be assembled from one library representing this expression state or it may comprise cassettes from a number of different expression states. The concatemers according to the invention are especially suitable for ligating into an artificial chromosome, which may be inserted into a host cell for coordinated expression. For this purpose, the variation among and between cassettes may be such as to minimise the chance of cross over as the host cell undergoes cell division such as through minimising the level of repeat sequences occurring in any one concatemer, since it is not an object of this embodiment of the invention to obtain recombination of concatemers with a segment in the host genome or an epitope of the host cells nor is it an object to obtain intra- or extra concatemeric recombination.

According to a preferred embodiment of the invention the concatemer comprises at least a first cassette and a second cassette, said first cassette being different from said second cassette. More preferably, the concatemer comprises cassettes, wherein substantially all cassettes are different. The difference between the cassettes may arise from differences between promoters, and/or expressible nucleotide sequences, and/or spacers, and/or introns and/or terminators.

The number of cassettes in a single concatemer is largely determined by the host species into which the concatemer is eventually to be inserted and the vector

through which the insertion is carried out. The concatemer thus may comprise at least 10 cassettes, such as at least 15, for example at least 20, such as at least 25, for example at least 30, such as from 30 to 60 or more than 60, such as at least 75, for example at least 100, such as at least 200, for example at least 500, such as at least 750, for example at least 1000, such as at least 1500, for example at least 2000 cassettes.

Each of the cassettes may be laid out as described above.

Thus, in a preferred embodiment a concatemer is used to denote a number of serially linked nucleotide cassettes, wherein at least two of the serially linked nucleotide units comprises a cassette having the basic structure

[rs<sub>2</sub>-SP-PR-X-TR-SP-rs<sub>1</sub>]

wherein

rs<sub>1</sub> and rs<sub>2</sub> together denote a restriction site,

SP denotes a spacer of at least two nucleotide bases,

PR denotes a promoter, capable of functioning in a cell,

X denotes an expressible nucleotide sequence,

TR denotes a terminator, and

SP denotes a spacer of at least two nucleotide bases.

wherein the variables of the cassette have the meaning as defined elsewhere in this specification. Optionally the cassettes comprise an intron sequence between the promoter and the expressible nucleotide sequence and/or between the terminator and the expressible nucleotide sequence as discussed above.

According to one aspect of the invention, a concatemer comprises cassettes with expressible nucleotide from different expression states, so that non-naturally occurring combinations or non-native combinations of expressible nucleotide sequences are obtained.

According to a preferred embodiment of the invention the concatemer comprises at least a first cassette and a second cassette, said first cassette being different from said second cassette. More preferably, the concatemer comprises cassettes, wherein substantially all cassettes are different. The difference between the

cassettes may arise from differences between promoters, and/or expressible nucleotide sequences, and/or spacers, and/or terminators, and/or introns.

The concatenation may be carried out in different ways.

5

Cassettes to be concatenated are normally excised from a vector or they are synthesised through PCR. After excision the cassettes may be separated from the vector through size fractionation such as gel filtration or through tagging of known sequences in the cassettes. The isolated cassettes may then be ligated together  
10 either through interaction between sticky ends or through ligation of blunt ends.

15

More preferably the cassettes may be concatenated without an intervening purification step through excision from a vector with two restriction enzymes, one leaving sticky ends on the cassettes and the other one leaving blunt ends in the vectors.

20

An alternative way of producing concatemers free of vector sequences would be to PCR amplify the cassettes from a single stranded primary vector. The PCR product must include the restriction sites RS2 and RS2' which are subsequently cleaved by its cognate enzyme(s). Concatenation can then be performed using the digested PCR product, essentially without interference from the single stranded primary vector template or the small double stranded fragments, which have been cut from the ends.

25

When the vectors comprising the cassettes are single stranded, the cassettes may be excised and be made double stranded through PCR techniques, which only prime the cassette sequence and not the vector sequence. Sticky ends can be made by cleaving with a restriction enzyme leaving sticky ends and the cassettes can be assembled without interaction from the single stranded vector fragments.

30

The concatemer may be assembled or concatenated by concatenation of at least two cassettes of nucleotide sequences each cassette comprising a first sticky end, a spacer sequence, a promoter, an expressible nucleotide sequence, a terminator, and a second sticky end.

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After concatenation has been completed, concatemers of the desired size may be selected through size selection, such as selection for concatemers having at least 10 cassettes, such as at least 15, for example at least 20, such as at least 25, for example at least 30, such as from 30 to 60 or more than 60, such as at least 75, for example at least 100, such as at least 200, for example at least 500, such as at least 750, for example at least 1000, such as at least 1500, for example at least 2000 cassettes. The number of cassettes in each concatemer may be controlled by size fractionation after concatenation, since the size of the concatemers is approximately proportional to the number of cassettes.

Preferably at least one inserted concatemer in each cell comprises a selectable marker. Selectable markers generally provide a means to select, for growth, only those cells which contain a vector. Such markers are of two types: drug resistance and auxotrophic. A drug resistance marker enables cells to detoxify an exogenously added drug that would otherwise kill the cell. Auxotrophic markers allow cells grow in media lacking an essential component by enabling cells to synthesise the essential component (usually an amino acid).

Illustrative and non-limiting examples of common selectable markers with a brief description of their mode of action follow:

#### Prokaryotic

- Ampicillin: Interferes with a terminal reaction in bacterial cell wall synthesis. The resistance gene (bla) encodes beta-lactamase which cleaves the beta-lactam ring of the antibiotic thus detoxifying it.
- Tetracycline: prevents bacterial protein synthesis by binding to the 30S ribosomal subunit. The resistance gene (tet) specifies a protein that modifies the bacterial membrane and prevents transport of the antibiotic into the cell.
- Kanamycin: binds to the 70S ribosomes and causes misreading of messenger RNA. The resistant gene (nptII) modifies the antibiotic and prevents interaction with the ribosome.
- Streptomycin: binds to the 30S ribosomal subunit, causing misreading of messenger RNA. The resistance gene (Sm) modifies the antibiotic and prevents interaction with the ribosome.
- Zeocin: this new bleomycin-family antibiotic intercalates into the DNA and cleaves it. The Zeocin resistance gene encodes a 13,665 dalton protein. This protein confers resistance to Zeocin by binding to the antibiotic and preventing it from binding DNA. Zeocin is effective on most aerobic cells and can be used for selection in mammalian cell lines, yeast, and bacteria.
- Auxotrophic markers.

#### Eukaryotic

- Hygromycin: a aminocyclitol that inhibits protein synthesis by disrupting ribosome translocation and promoting mistranslation. The resistance gene (hph) detoxifies hygromycin -B- phosphorylation.

- Histidinol: cytotoxic to mammalian cells by inhibiting histidyl-tRNA synthesis in histidine free media. The resistance gene (hisD) product inactivates histidinol toxicity by converting it to the essential amino acid, histidine.
- Neomycin (G418): blocks protein synthesis by interfering with ribosomal functions. The resistance gene ADH encodes amino glycoside phosphotransferase which detoxifies G418.
- Uracil: Laboratory yeast strains carrying a mutated gene which encodes orotidine -5'- phosphate decarboxylase, an enzyme essential for uracil biosynthesis, are unable to grow in the absence of exogenous uracil. A copy of the wild-type gene (ura4+, *S. pombe* or URA3 *S. cerevisiae*) carried on the vector will complement this defect in transformed cells.
- Adenosine: Laboratory strains carrying a deficiency in adenosine synthesis may be complemented by a vector carrying the wild type gene, ADE 2.
- Amino acids: Vectors carrying the wild-type genes for LEU2, TRP 1, HIS 3 or LYS 2 may be used to complement strains of yeast deficient in these genes.
- Zeocin: this new bleomycin-family antibiotic intercalates into the DNA and cleaves it. The Zeocin resistance gene encodes a 13,665 dalton protein. This protein confers resistance to Zeocin by binding to the antibiotic and preventing it from binding DNA. Zeocin is effective on most aerobic cells and can be used for selection in mammalian cell lines, yeast, and bacteria.

The number of concatemers in one single cell may be at least one concatemer per cell, preferably at least 2 concatemers per cell, more preferably 3 per cell, such as 4 per cell, more preferably 5 per cell, such as at least 5 per cell, for example at least 6 per cell, such as 7, 8, 9 or 10 per cell, for example more than 10 per cell. As described above, each concatemer may preferably comprise up to 1000 cassettes, and it is envisaged that one concatemer may comprise up to 2000 cassettes. By inserting up to 10 concatemers into one single cell, this cell may thus be enriched with up to 20,000 new expressible genes, which under suitable conditions may be turned on and off by regulation of the regulatable promoters. However it may be more preferable to provide cells having anywhere between 10 and 1000 novel genes, such as 20-900 novel genes, for example 30 to 800 novel genes, such as 40 to 700 novel genes, for example 50 to 600 novel genes, such as from 60 to 300 novel genes. The genes may advantageously be located on 1 to 10 such as from 2 to 5 different concatemers in the cells. Each concatemer may advantageously comprise from 10 to 1000 genes, such as from 10 to 750 genes, such as from 10 to 500 genes, such as from 10 to 200 genes, such as from 20 to 100 genes, for example from 30 to 60 genes.

The concatemers may be inserted into the host cells according to any known transformation technique, preferably according to such transformation techniques that ensure stable and not transient transformation of the host cell. The concatemers may thus be inserted as an artificial chromosome which is replicated by the cells as

they divide or they may be inserted into the chromosomes of the host cell. The concatemer may also be inserted in the form of a plasmid such as a plasmid vector, a phage vector, a viral vector, a cosmid vector, that is replicated by the cells as they divide. Any combination of the three insertion methods is also possible. One or more  
5 concatemers may thus be integrated into the chromosome(s) of the host cell and one or more concatemers may be inserted as plasmids or artificial chromosomes. One or more concatemers may be inserted as artificial chromosomes and one or more may be inserted into the same cell via a plasmid.

10 The basic requirements for a functional artificial chromosome have been described in US 4,464,472, the contents of which is hereby incorporated by reference. An artificial chromosome or a functional minichromosome, as it may also be termed must comprise a DNA sequence capable of replication and stable mitotic  
15 maintenance in a host cell comprising a DNA segment coding for centromere-like activity during mitosis of said host and a DNA sequence coding for a replication site recognized by said host.

Suitable artificial chromosomes include a Yeast Artificial Chromosome (YAC) (see e.g. Murray et al, Nature 305:189-193; or US 4,464,472), a mega Yeast Artificial  
20 Chromosome (mega YAC), a Bacterial Artificial Chromosome (BAC), a mouse artificial chromosome, a Mammalian Artificial Chromosome (MAC) (see e.g. US 6,133,503 or US 6,077,697), an Insect Artificial Chromosome (BUGAC), an Avian Artificial Chromosome (AVAC), a Bacteriophage Artificial Chromosome, a Baculovirus Artificial Chromosome, a plant artificial chromosome (US 5,270,201), a  
25 BIBAC vector (US 5,977,439) or a Human Artificial Chromosome (HAC).

The artificial chromosome is preferably so large that the host cell perceives it as a "real" chromosome and maintains it and transmits it as a chromosome. For yeast  
30 and other suitable host species, this will often correspond approximately to the size of the smallest native chromosome in the species. For *Saccharomyces*, the smallest chromosome has a size of 225 Kb.

MACs may be used to construct artificial chromosomes from other species, such as insect and fish species. The artificial chromosomes preferably are fully functional  
35 stable chromosomes. Two types of artificial chromosomes may be used. One type,

referred to as SATACs [satellite artificial chromosomes] are stable heterochromatic chromosomes, and the other type are minichromosomes based on amplification of euchromatin.

5 Mammalian artificial chromosomes provide extra-genomic specific integration sites for introduction of genes encoding proteins of interest and permit megabase size DNA integration, such as integration of concatemers according to the invention.

10 According to another embodiment of the invention, the concatemer may be integrated into the host chromosomes or cloned into other types of vectors, such as a plasmid vector, a phage vector, a viral vector or a cosmid vector.

15 A preferable artificial chromosome vector is one that is capable of being conditionally amplified in the host cell, e.g. in yeast. The amplification preferably is at least a 10 fold amplification. Furthermore, it is advantageous that the cloning site of the artificial chromosome vector can be modified to comprise the same restriction site as the one bordering the cassettes described above, i.e. RS2 and/or RS2'.

20 It is also conceivable that recombination can be used to generate concatemers, e.g. through the modification of techniques like the Creator system (Clontech) which uses the Cre-loxP mechanism (ref: Sauer B 1993 Methods Enzymol 225:890-900) to directionally join DNA molecules by recombination or like the Gateway system (Life Technologies, US 5,888,732) using lambda *att* attachment sites for directional recombination (Landy A 1989, Ann Rev Biochem 58:913). It is envisaged that also  
25 lambda *cos* site dependent systems can be developed to allow concatenation.

The concatemer may be assembled or concatenated by concatenation of at least two cassettes of nucleotide sequences each cassette comprising a first sticky end, a spacer sequence, a promoter, an expressible nucleotide sequence, a terminator,  
30 and a second sticky end. A flow chart of the procedure is shown in figure 10a.

Preferably concatenation further comprises

starting from a primary vector [RS1-RS2-SP-PR-X-TR-SP-RS2'-RS1'],  
wherein X denotes an expressible nucleotide sequence,  
35 RS1 and RS1' denote restriction sites,



RS2 and RS2' denote restriction sites different from RS1 and RS1',

SP denotes a spacer sequence of at least two nucleotides,

PR denotes a promoter,

TR denotes a terminator,

- 5           i)       cutting the primary vector with the aid of at least one restriction enzyme specific for RS2 and RS2' obtaining cassettes having the general formula [rs<sub>2</sub>-SP-PR-X-TR-SP-rs<sub>1</sub>] wherein rs<sub>1</sub> and rs<sub>2</sub> together denote a functional restriction site RS2 or RS2',
- 10           ii)       assembling the cut out cassettes through interaction between rs<sub>1</sub> and rs<sub>2</sub>.

According to an especially preferred embodiment, vector arms each having a RS2 or RS2' in one end and a non-complementary overhang or a blunt end in the other end are added to the concatenation mixture together with the cassettes described above to further simplify the procedure (see Fig. 10b). One example of a suitable vector for providing vector arms is disclosed in Fig. 16 TRP1, URA3, and HIS3 are auxotrophic marker genes, and AmpR is an antibiotic marker gene. CEN4 is a centromer and TEL are telomeres. ARS1 and PMB1 allow replication in yeast and E. coli respectively. BamH I and Asc I are restriction enzyme recognition sites. The nucleotide sequence of the vector is set forth in SEQ ID NO 4. The vector is digested with BamHI and AscI to liberate the vector arms, which are used for ligation to the concatemer.

15

20

The ratio of vector arms to cassettes determines the maximum number of cassettes in the concatemer as illustrated in figure 18a and b. The vector arms preferably are artificial chromosome vector arms such as those described in Fig. 16. Figure 17 illustrates the synthesis of concatamers from entry vector libraries.

25

It is of course also possible to add stopper fragments to the concatenation solution, the stopper fragments each having a RS2 or RS2' in one end and a non-complementary overhang or a blunt end in the other end. The ratio of stopper fragments to cassettes can likewise control the maximum size of the concatemer.

30

As an alternative to providing vector arms for the concatenation procedure is possible to ligate the concatemer into an artificial chromosome selected from the

35

group comprising yeast artificial chromosome, mega yeast artificial chromosome, bacterial artificial chromosome, mouse artificial chromosome, human artificial chromosome.

5 The number of concatemers in one single cell may be at least one concatemer per cell, preferably at least 2 concatemers per cell, more preferably 3 per cell, such as 4 per cell, more preferably 5 per cell, such as at least 5 per cell, for example at least 6 per cell; such as 7, 8, 9 or 10 per cell, for example more than 10 per cell. As described above, each concatemer may preferably comprise up to 1000 cassettes, and it is envisaged that one concatemer may comprise up to 2000 cassettes. By  
10 inserting up to 10 concatemers into one single cell, this cell may thus be enriched with up to 20,000 heterologous expressible genes, which under suitable conditions may be turned on and off by regulation of the regulatable promoters.

15 Often it is more preferable to provide cells having anywhere between 10 and 1000 heterologous genes, such as 20-900 heterologous genes, for example 30 to 800 heterologous genes, such as 40 to 700 heterologous genes, for example 50 to 600 heterologous genes, such as from 60 to 300 heterologous genes or from 100 to 400 heterologous genes which are inserted as 2 to 4 artificial chromosomes each  
20 containing one concatemer of genes. The genes may advantageously be located on 1 to 10 such as from 2 to 5 different concatemers in the cells. Each concatemer may advantageously comprise from 10 to 200 genes, such as from 20 to 100 genes, for example from 30 to 60 genes, or from 50 to 100 genes.

## 25 EXAMPLES

**Example 1:** Rescue of expression cassettes from EVAC clones and creation of new EVAC libraries

30 Cells contain EVAC libraries with the following characteristics:

- EVAC markers: Uracil and Tryptophan
- cDNA libraries used for EVAC construction, , 20 % carrot (root), 20% phaffia (whole organism), 20% carotenoid gene library, 20% Actinidia deliciosa (whole organism), 20% Cantharellus cibarius (whole organism)
- 35 • Mixture of entry vectors used to clone the cDNAs, e.g., pEVE4, pEVE5, pEVE13

- 1) Isolate total DNA (as intact as possible in order to make cassette isolation easier) from an overnight culture using Easy-DNA™ Kit (Invitrogen).
- 2) Digest over night 10-15 µg chromosomal DNA with 5 units of *Ascl* per µg of DNA. The *Ascl* digests the EVAC into single expression cassettes and the rest of the yeast genome into on average 500 kb fragments.
- 3) The digested DNA is purified on a "PCR" purification column High Pure™ PCR Product Purification Kit (Roche) (or a filter which holds back fragments bigger then 10 kb) where the chromosomal fragments will be retained and primarily the expression cassettes will be recovered.
- 4) Digest pEVE1 with *Ascl* and dephosphorylate. (pEVE1 is a modified entry vector, with no linker region in between the *Ascl* sites).
- 5) Clone expression cassettes into pEVE1 by mixing 0.5 µg of purified expression cassettes, 200ng of entry vector (*Ascl* cut and dephosphorylated) and 0.5 U of T4-DNA ligase (1u/µl) (Roche) in 1 x ligation buffer (Roche). Ligate over night at 16°C.
- 6) The ligation mixture is then used to transform *E.coli* by electroporation using 1 µl of 1:10 diluted ligation mixture per transformation (current protocols in molecular biology, section 1.8.4).
- 7) The synthesis of new EVACs can then be done as described earlier (See examples below).

New EVACs can be made just from these cassettes or by mixing these with cassettes from libraries not previously used. The use of cassettes just from this library would give a larger representation of all possible combinations of the selected genes. This most likely produces more variations of certain classes of molecules and is thus used later on in the evolution process when yeasts with characteristics close to the ideal have been identified.

**Example 2:** Physical re-isolation and re-transformation of EVACs.

1. The EVAC containing population is grown in 5 ml of YPD to an OD<sub>600</sub> > 1.0
2. Two 100 µl plugs of total DNA are produced as described in BioRad's "CHEF genomic DNA plug kits" manual, Procure n.2
3. EVACs are purified and isolated:

- 5
- a. Plugs are cut and loaded into 3 slots of a pulsed field gel
- b. Run PFGE
- i. For EVACs < 1000 kb : Chef III, 1% Agarose, 1/2 strength TBE, 6V/cm, 14°C, 120° angle, 50 – 90 sec. Switch time, 22 h run-time.
- 10
- ii. For EVACs > 1000 kb. Chef III, 1% Agarose, 1/2 strength TBE, 6V/cm, 14°C, 120° angle, 60-120 sec. Switch time, 24 h runtime
- c. stain one lane to identify position of EVACs
- d. cut corresponding part of the two non-stained lanes and digest the agarose by agarase treatment following standard procedures e.g. Pulsed Field Gel Electrophoresis. A practical approach.(Ed. A.P. Monaco) Oxford University Press 1995.
- 15
- e. Concentrate agarased preparation to 100 µL by ultrafiltration.(e.g. Microcon YM-30, Millipore)
- f. add 400 TE to retentate and repeat concentration step. Repeat and concentrate to 25 µL
4. EVACs are transformed into yeast as before.

20 **Example 3:** Amplification of EVACs up to 20% of total host DNA prior to EVAC isolation and re-transformation

25 A YAC vector containing a conditional centromere (the GAL1 promoter in front of the centromere) and a heterologous thymidine kinase (TK) marker can be amplified to constitute up to 20 % of the total DNA content in yeast cells. The centromere is inactivated by inducing transcription from a strong promoter (GAL1) towards conserved sequences of the centromere. The cells are propagated in media containing thymidine, sulfanilamide and methotrexate which selects for cells containing multiple copies of the YAC. (Smith, D. R. et al., 1990, Proc. Natl. Acad. USA, Vol 87, pp. 8242-8246).

30 **Example 4:** Sexual crosses of yeast cell populations. (Using selective media for diploid selection)

**Cell populations:**

Cell populations with 2 EVACs/cell are obtained by transforming cells that already contain an EVAC with a second EVAC.

- 5     Cell population 1 contains EVACs of type 1 and 2 and the host cells are of mating type  $\alpha$ .

EVACs of type 1:

- Markers: URA 3, TRP 1, NPT<sup>II</sup>
- 10   • cDNA libraries used to make EVACs, e.g., carrot (root), Aloe humilis (flower), Narcissus pseudonarcissus (flower), Lycopersicon esculentum (fruit), Olea europaea (leaves)
- Mixture of entry vectors each library is cloned in, e.g., pEVE4, pEVE5, pEVE13 & pEVE14

15

EVACs of type 2:

- Markers: LEU 2, TRP 1, NPT<sup>II</sup>
- cDNA libraries e.g, phaffia (whole organism), Anubias Barteri (leaves), Acremonium diospyri (whole organism), Phycomyces blakesleeanus (whole organism),
- 20   Mucor azygosporus (whole organism)
- Mixture of entry vectors each library is cloned in, e.g., pEVE4, pEVE5, pEVE13 & pEVE14

25

Cell population 2 contains EVACs of type 3 and 4 and the host cells are of mating type  $\alpha$ .

EVACs of type 3:

- Markers: URA 3, HIS 3, NPT<sup>II</sup>
- cDNA libraries used, e.g., mouse (skin and placenta), sea urchin (whole organism), carassius auratus, (whole organism), paracheirodon axelrodi (whole organism), cucumaria japonica (whole organism).
- 30   • Mixture of entry vectors each library is cloned in, e.g., pEVE4, pEVE5, pEVE13 & pEVE14

EVACs of type 4:

- Markers: LEU 2, HIS 3, NPT<sup>II</sup>
- cDNA libraries used, e.g., *Hierodula gransid* (head), mouse (eyes), *Dyscophus insularis* (skin), *Gnathonemus petersii* (head), *Diapherodes jamaicensis* (head)
- Mixture of entry vectors each library is cloned in, e.g., pEVE4, pEVE5, pEVE13 & pEVE14

Cell population 3 contains EVACs of type 1 and 2 and the host cells are a 50/50 mixture of mating types  $\alpha$  and  $\alpha$ .

- cDNA libraries used to produce EVACs, e.g., *Skimmia jap.* *Rubella* (leaves), *Neurospora crassa* (whole organism), *Mytilus coruscus* (whole organism), *Pinus pinaster* (leaves), *Carica papaya* (fruit)

Cell population 4 contains EVACs of type 3 and 4 and the host cells are a 50/50 mixture of mating types  $\alpha$  and  $\alpha$ .

- cDNA libraries used to produce EVACs, e.g., *Cantharellus cibarius* (whole organism), *Rhizophora mangle* (leaves), *Fucus vesiculosus* (leaves), *Halichondria okadai* (whole organism)

**Remixing round 1:**

- 1) Construction of Diploid population. Mix cells from freshly grown overnight cultures of cell populations 1 and 2. Distribute cells in agar plates (the plates should allow growth of both haploid strains). Allow mating to proceed for at least 4 hours at 30°C, then wash cells off from plates and incubate the mating mixture in a liquid selective medium that will select for the diploid genotype which contains the 4 different types of EVACs (-URA3, -TRP1, -LEU2, -HIS3).

- 2) Biological Screen.

- a. Induce heterologous genes
- b. The diploid cell population is screened for the relevant pharmaceutical property(ies) and a subset of this population is selected

- c. Obtain a 10 times representation of selected population by letting it grow on selective medium.
- d. Divide selected population in 3 portions, (i) store, (ii) sporulate, (iii) keep for re-screening at a higher selection hurdle

5      3) Sporulation in liquid media of selected subpopulation.

- a. Grow portion (ii) of selected diploid population to an OD<sub>600</sub> of 2.5 to 3.0 ( $\sim 8 \times 10^7$  cells/ml) in selective medium.
- b. Transfer 1 ml culture to a sterile, disposable 15 ml polypropylene tube and centrifuge 5 min at 1200 x g
- 10      c. Pour off the supernatant and re-suspend cells in 5 ml sterile water. Vortex to re-suspend cells and spin as in step 2.
- d. Pour off supernatant and re-suspend cells in 1 ml of sporulation medium
- e. Shake for 2 to 3 days at  $\geq 350$  rpm, 30°C, and examine the culture
- 15      microscopically for spore formation

*Sporulation medium, per liter:*

- 10g potassium acetate (1%)
- 1g yeast extract
- 20      0.5 g dextrose

4) Formation of random spores

- a. Pellet 1 ml of sporulation culture
- b. Re-suspend all the cells from a 1 ml sporulation culture in 5 ml water
- 25      c. Add 0.5 ml of a 10000 U Zymolyase-20T solution (ICN Immunobiologicals) and 10  $\mu$ l of 2-mercaptoethanol. (The Zymolyase will kill any diploid cells that did not sporulate as well as haploid cells that have not mated).
- d. Incubate overnight at 30°C with gentle shaking.
- 30      e. Add 5 ml of 1.5% Nonidet P-40 (NP-40). Transfer the suspension to a 15 ml disposable tube and set 15 min. on ice.
- f. Vortex in the presence of glass beads 30 sec. at 50% to 75% full power, then set on ice 2 min. Repeat twice.

- g. Centrifuge spores 10 min. at 1200 x g. Aspirate or pour off supernatant and re-suspend in 5 ml of 1.5% NP-40. Vortex vigorously. Repeat twice.
- h. Vortex in the presence of glass beads as in step f (with repeats).
- 5 i. Examine the spores by phase contrast microscopy to ensure that no more spores remain stuck together.
- j. (If spores remain stuck to each other, add 2 ml glass beads (Type I, Sigma) and shake 30 min. at 300 rpm in an Erlenmeyer flask at 30°C. Let the beads settle and remove the supernatant containing the spores.)
- 10 k. Centrifuge spores 10 min. at 1200 x g. Aspirate or pour off supernatant and re-suspend in 5 ml of water. Vortex vigorously. Repeat.
- l. Count a 10-fold dilution of the treated spores using a hemocytometer.

15 5) Selection of haploid cells with at least 1 EVAC:

- a. Dilute the spores to get  $10^3$  spores/ml in a media that contains G418. (The antibiotic will kill the newly formed haploid cells that do not contain at least 1 EVAC).
- 20 b. Allow spores to germinate without allowing cultures  $OD_{600}$  to raise above 0.5 (in order to avoid new sexual crosses to occur).
- c. Centrifuge 10 min. at 1200 x g and aspirate or pour off supernatant.

25 The newly formed haploid cell population consists of a 50/50 mixture of a and  $\alpha$  cells which have any where from 1 to 4-5 EVACs each with most of the cells containing 2 EVACs.

**Remixing round 2:**

The newly formed haploid population is mated with population 3.

30

6) Construction of Diploid population.

- a. A mixture of the 2 populations is grown overnight.
- b. Cells are centrifuged and the supernatant is poured off.
- c. Cells are re-suspended in as small an amount of rich medium as possible.
- 35



- 5
- d. Distribute cells on agar plates and allow mating to proceed for at least 4 hours at 30°C and then wash cells off from plates.
  - e. Incubate the mating mixture in a liquid selective medium that will select for the 4 different markers (-URA3, -TRP1, -LEU2, -LYS2). This media selects for at least 70% of all possible diploid combinations. Some haploid cells which contain the 4 markers will also be able to survive at this point but the next time Zymolyase is used, the haploid cells will be killed.

10 7) Biological Screen.

- 15
- a. Combine the population obtained in point 6e) with portion (iii) of the population obtained in point 2d).
  - b. Induce heterologous genes
  - c. The cell population is screened for the relevant pharmaceutical property(ies) and a subset of these populations are selected
  - d. Obtain a 10 times representation of selected populations by letting them grow on selective medium.
  - e. Divide selected population in 3 portions, (i) store, (ii) sporulate, (iii) keep for re-screening at a higher selection hurdle

20 8) Repeat points 3, 4 and 5

**Remixing round 3:**

25 The newly formed haploid population is mated with population 4.

9) Construction of Diploid population.

- 30
- a. A mixture of the 2 populations is grown overnight.
  - b. Cells are centrifuged and the supernatant is poured off.
  - c. Cells are re-suspended in as small an amount of rich medium as possible.
  - d. Distribute cells on agar plates and allow mating to proceed for at least 4 hours at 30°C and then wash cells off from plates.
  - e. Incubate the mating mixture in a liquid selective medium that will select for the 4 different markers (-URA3, -TRP1, -LEU2, -LYS2). This
- 35

media selects for at least 90% of all possible diploid combinations. Some haploid cells which contain the 4 markers will also be able to survive at this point but the next time Zymolyase is used, the haploid cells will be killed.

5

10) Biological Screen.

- a. Combine the population obtained in point 9e) with portion (iii) of the population obtained in point 7e).
- b. Induce heterologous genes
- 10 c. The cell population is screened for the relevant pharmaceutical property(ies) and a subset of these populations are selected
- d. Obtain a 10 times representation of selected populations by letting them grow on selective medium.
- e. Divide selected population in 3 portions, (i) store, (ii) sporulate, (iii) 15 keep for re-screening at a higher selection hurdle

11) Repeat points 3, 4 and 5

Repeat till desired pharmaceutical properties have been obtained.

20

**Example 5:** Sexual crosses of yeast cell populations. (Using a fluorescence activated cell sorter (FACS) for diploid selection)

This procedure is very similar to the one described in example 2 but instead of using selective media to select for diploid cells, this selection is done simultaneously with the biological screening.

25

**Remixing round 1:**

- 30 1) Construction of Diploid population. Mix cells from freshly grown overnight cultures of each cell population. Distribute cells in agar plates (the plates should allow growth of both haploid strains). Allow mating to proceed for at least 4 hours at 30°C, then wash cells off from plates and incubate the mating mixture in a rich medium.
- 35 2) Biological Screen.

- a. Induce heterologous genes
- b. The cell population is screened for the relevant pharmaceutical property(ies) and for ploidy. A subset of this population that has the required biological property and is diploid is taken forward.
- 5 c. Obtain a 10 times representation of selected population.
- d. Divide selected population in 3 portions, (i) store, (ii) sporulate, (iii) keep for re-screening at a higher selection hurdle
- 3) Repeat remaining protocol has described in example 2.

10 Thus when using FACS for the biological screening it is better to use this method since it shortens each screening round by 24-36 hours.

**Example 6:** Sorting of mating types after formation of haploid cells.

15 Keeping haploid cells from mating with each other is very difficult and requires very precise control. Thus an alternative is to sort haploid cells every time after haploid formation. For this purpose it is possible to use antibodies (against a and  $\alpha$  receptor) or a and  $\alpha$  mating factors (conjugated with suitable flouorofors/chromofors) to label the cells of different mating types. The cells are then sorted in a FACS. (In principle  
20 as in chapter 5 of Flow cytometry : a practical approach / edited by Michael G. Ormerod. 3rd ed., 2000, Oxford university press).

**Example 7:** Remixing of spores.

25 Another possibility is to mix the spores of 2 different populations and then do random spore separation and mating.

**Example 8:** Combination of sexual remixing with physical rescue of expression cassettes

30

Every so often in the evolution programme it is advisable to use physical rescue of expression cassettes and transformation of new EVACs into new host cells in order to avoid selection of phenotypes that are due to the creation of resistant mechanisms and mutations in the host cell.

35

**Example 9:** Biological screening of haploid cells

It is also possible to screen for cells in their haploid state. In this procedure it is essential to have optimised for 90% plus mating efficiency in order not to lose the genetic content of the haploid cells in the remixing step.

**Example 10:** Preparation of EVACs (Evolvable Artificial Chromosomes)

1. Essentially full length cDNA libraries are made.
2. cDNA libraries are made using a pool of 4 entry vectors: pEVE4, pEVE5, pEVE8 and pEVE9 in a proportion of 30:30:1:30. See Figures 12, 13, 14, and 15.
3. Each cDNA library is normalised essentially as method 4 described in Bonaldo, MF et al. (1996) Genome Res. 6: 791-806.
4. Coding sequences from a non-normalised yeast (*Saccharomyces cerevisiae*) cDNA library are amplified by PCR and are used as driver for subtractive hybridization against single stranded circular DNA prepared from the normalized library (Bonaldo, MF et al. (1996) Genome Res. 6: 791-806), in order to remove household genes. Remaining single stranded circles are purified, converted to double stranded DNA and used to transform E.coli DH5 $\alpha$ .
5. EVAC (Evolvable Artificial Chromosome) containing cell populations are made using 10 different normalised and enriched cDNA libraries in each.

**Preparation of expression cassettes**

1. Inoculate 5 ml of LB-medium (Sigma) containing 100  $\mu$ g/L ampicillin with library inoculum corresponding to a 10<sup>4</sup> fold representation of library. Grow overnight.
2. make plasmid miniprep from 1.5 ml of culture (E.g. Qiaprep spin miniprep kit)
3. digest plasmid w. Srf 1
4. dephosphorylate fragments and heat inactivate phosphatase( 20 min, 80°C)
5. digest w. Asc1
6. run 1/10 of reaction in 1% agarose gel to estimate amount of fragment

**Preparation of pYAC4-Asc arms**

1. inoculate 150 ml of LB medium (Sigma) with a single colony of DH5 $\alpha$  containing pYAC4-AscI
2. grow to OD<sub>600</sub> ~ 1, harvest cells and make plasmid preparation
3. digest 100 $\mu$ g pYAC4-AscI w. BamH1 and AscI
4. dephosphorylate fragments and heat inactivate phosphatase( 20 min, 80°C)
5. purify fragments(e.g. Qiaquick Gel Extraction Kit)
6. run 1 % agarose gel to estimate amount of fragment

**EVAC Synthesis**

1. mix expression cassette fragments with YAC-arms so that cassette/arm ratio is ~1000/1
2. if needed concentrate mixture (use e.g. Microcon YM30) so fragment concentration > 75 ng/ $\mu$ L of reaction
3. add 1 U T4 DNA ligase, incubate 16°C, 1-3 h . Stop reaction by adding 1  $\mu$ L of 500 mM EDTA
4. run pulsed field gel (CHEF III, 1% LMP agarose, ½ strength TBE, angle 120; temperature 12 C, voltage 5.6V/cm, switch time ramping 5 – 25 s, run time 30 h) Load sample in 2 lanes.
5. Stain part of the gel that contains molecular weight markers
6. cut sample lanes corresponding to MW. 100 – 500 kb
7. agarose gel in high NaCL agarase buffer . 1 u agarase / 100 mg gel
8. concentrate preparation to < 20  $\mu$ L

**Example 11: EVAC transformation using electroporation**

100 ml of YPD is inoculated with one yeast colony and grown to OD<sub>600</sub>  $\cong$  1.3 to 1.5. The culture is harvested by centrifuging at 4000  $\times$  g and 4°C. The cells are re-suspended in 16 ml sterile H<sub>2</sub>O. Add 2 ml 10  $\times$  TE buffer, pH 7.5 and swirl to mix.

Add 2 ml 10  $\times$  lithium acetate solution (1 M, pH 7.5) and swirl to mix. Shake gently 45 min at 30°C. Add 1.0 ml 0.5 M DTE while swirling. Shake gently 15 min at 30°C. The yeast suspension is diluted to 100 ml with sterile water. The cells are washed and concentrated by centrifuging at 4000  $\times$  g, resuspending the pellet in 50 ml ice-cold sterile water, centrifuging at 4000  $\times$  g, resuspending the pellet in 5 ml ice-cold

sterile water, centrifuging at  $4000 \times g$  and resuspending the pellet in 0.1 ml ice-cold sterile 1 M sorbitol. The electroporation was done using a *Bio-Rad Gene Pulser*. In a sterile 1.5-ml microcentrifuge tube 40  $\mu$ l concentrated yeast cells were mixed with 5  $\mu$ l 1:10 diluted EVAC preparation. The yeast-DNA mix is transferred to an ice-cold 0.2-cm-gap disposable electroporation cuvette and pulsed at 1.5 kV, 25  $\mu$ F, 200  $\Omega$ . 1 ml ice-cold 1 M sorbitol is added to the cuvette to recover the yeast. Aliquots are spread on selective plates containing 1 M sorbitol. Incubate at 30°C until colonies appear.

**Example 12:** Transformation of EVACs (Evolvable Artificial Chromosomes) into hosts that already contain EVACs

1. Grow the EVAC cell population to mid-log,  $2 \times 10^6$  to  $2 \times 10^7$  cells/ml in liquid medium, at 30°C and with aeration, under selective conditions for the EVACs.
2. Spin to pellet cells at  $400 \times g$  for 5 minutes; discard supernatant.
3. Resuspend cells in a total of 9 ml TE, pH 7.5. Spin to pellet cells and discard supernatant.
4. Gently resuspend cells in 5 ml 0.1 M Lithium/Cesium Acetate solution, pH 7.5.
5. Incubate at 30°C for 1 hour with gentle shaking.
6. Spin at  $400 \times g$  for 5 minutes to pellet cells and discard supernatant.
7. Gently resuspend in 1 ml TE, pH 7.5. Cells are now ready for transformation.
8. In a 1.5 ml tube combine:
  - 100  $\mu$ l yeast cells
  - 5  $\mu$ l carrier DNA (10 mg/ml)
  - 5  $\mu$ l Histamine Solution
  - 5/100 of an EVAC preparation in a 10  $\mu$ l volume (max). (One EVAC preparation is made of 100  $\mu$ g of entry vector library plasmid mixture)
9. Gently mix and incubate at room temperature for 30 minutes.
10. In a separate tube, combine 0.8 ml 50% (w/v) PEG 4000 and 0.1 ml TE and 0.1 ml of 1 M LiAc for each transformation reaction. Add 1 ml of this PEG/TE/LiAc mix to each transformation reaction. Mix cells into solution with gentle pipetting.
11. Incubate at 30°C for 1 hour.
12. Heat shock at 42°C for 15 minutes; cool to 30°C.
13. Pellet cells in a microcentrifuge at high speed for 5 seconds and remove supernatant.

14. Resuspend in 200 µl of rich media and plate in appropriate selective media

15. Incubate at 30°C for 48-120 hours until transformed colonies appear.

**Example 13: Rare restriction enzymes with recognition sequence and cleavage points**

In this example, rare restriction enzymes are listed together with their recognition sequence and cleavage points.

W = A or T; N = A, C, G, or T

**13 a) Unique, palindromic overhang**

Ascl	GG <sup>^</sup> CGCG <sub>CC</sub>
AsiSI	GCG <sub>AT</sub> <sup>^</sup> CGC
CciNI	GC <sup>^</sup> GGCC <sub>GC</sub>
CspBI	GC <sup>^</sup> GGCC <sub>GC</sub>
FseI	GG <sub>CCG</sub> <sup>^</sup> CC
MchAI	GC <sup>^</sup> GGCC <sub>GC</sub>
NotI	GC <sup>^</sup> GGCC <sub>GC</sub>
PacI	TTA <sub>AT</sub> <sup>^</sup> TAA
SbfI	CC <sub>TGCA</sub> <sup>^</sup> GG
SdaI	CC <sub>TGCA</sub> <sup>^</sup> GG
SgfI	GCG <sub>AT</sub> <sup>^</sup> CGC
SgrAI	CR <sup>^</sup> CCGG <sub>YG</sub>
Sse232I	CG <sup>^</sup> CCGG <sub>CG</sub>
Sse8387I	CC <sub>TGCA</sub> <sup>^</sup> GG

**13b) No overhang**

BstRZ246I	ATTT <sup>^</sup> AAAT
BstSWI	ATTT <sup>^</sup> AAAT
MspSWI	ATTT <sup>^</sup> AAAT
MssI	GTTT <sup>^</sup> AAAC
PmeI	GTTT <sup>^</sup> AAAC
SmiI	ATTT <sup>^</sup> AAAT
SrfI	GCCC <sup>^</sup> GGGC
Swal	ATTT <sup>^</sup> AAAT

**13c) Non-palindromic and/or variable overhang**

AarI	CACCTGCNNNN <sup>^</sup> NNNN <sub>CC</sub>
Abel	CC <sup>^</sup> TCA <sub>GC</sub>
Alol	<sup>^</sup> NNNNN <sub>NNNNNN</sub> NGAACNNNNNNNTCCNNNNNNNN <sub>NNNNN</sub> <sup>^</sup>
Bael	<sup>^</sup> NNNNN <sub>NNNNNNNNNN</sub> NACNNNNNGTAYCNNNNNNNN <sub>NNNNN</sub> <sup>^</sup>
BbvCI	CC <sup>^</sup> TCA <sub>GC</sub>

	CpoI	CG^GWC_CG
	CspI	CG^GWC_CG
	Pfl27I	RG^GWC_CY
	Ppil	^NNNNN_NNNNNNNGAACNNNNNCTCNNNNNNNN_NNNNN^
5	PpuMI	RG^GWC_CY
	PpuXI	RG^GWC_CY
	Psp5II	RG^GWC_CY
	PspPPI	RG^GWC_CY
	RsrII	CG^GWC_CG
10	Rsr2I	CG^GWC_CG
	SanDI	GG^GWC_CC
	SapI	GCTCTTCN^NNN_
	SdiI	GGCCN_NNN^NGGCC
	SexAI	A^CCWGG_T
15	SfiI	GGCCN_NNN^NGGCC
	Sse1825I	GG^GWC_CC
	Sse8647I	AG^GWC_CT
	VpaK32I	GCTCTTCN^NNN_

20

12d) Meganucleases

	I-Sce I	TAGGGATAA_CAGG^GTAAT
	I-Ceu I	ACGGTC_CTAA^GGTAG
25	I-Cre I	AAACGTC_GTGA^GACAGTTT
	I-Sce II	GGTC_ACCC^TGAAGTA
	I-Sce III	GTTTTGG_TAAC^TATTTAT
	Endo. Sce I	GATGCTGC_AGGC^ATAGGCTTGTTTA
	PI-Sce I	GG_GTGC^GGAGAA
30	PI-Psp I	TGGCAAACAGCTA_TTAT^GGGTATTATGGGT
	I-Ppo I	CTCTC_TTAA^GGTAG
	HO	TTTCCGC_AACA^GT
	I-Tev I	NN_NN^NNTCAGTAGATGTTTTCTTGGTCTACCGTTT

35

More meganucleases have been identified, but their precise sequence of recognition has not been determined, see e.g. [www.meganuclease.com](http://www.meganuclease.com)

#### **Example 14: Concatemer size limitation experiments (use of stoppers)**

40

Materials used:

pYAC4 (Sigma. Burke et al. 1987, science, vol 236, p 806) was digested with EcoRI and BamHI, and dephosphorylated.

pSE420 (invitrogen) was linearised using EcoRI and used as the model fragment for concatenation.

45

T4 DNA ligase (Amersham-pharmacia biotech) was used for ligation according to manufacturers instructions.



Method: Fragments and arms were mixed in the ratios (concentrations are arbitrary units) indicated on figures. Ligation was allowed to proceed for 1 h at 16°C. Reaction was stopped by the addition of 1  $\mu$ L 500 mM EDTA. Products were analysed by standard agarose GE (1 % agarose, ½ strength TBE) or by PFGE (CHEF III, 1% LMP agarose, ½ strength TBE, angle 120, temperature 12 °C, voltage 5.6V/cm, switch time ramping 5 – 25 s, run time 30 h)

The results are shown in Figure 18a and 18b.

**Example 15: Expression of different patterns “phenotypes” obtained using the same yeast clones under different expression conditions**

Yeast cells comprising a library of artificial chromosomes comprising genes derived from *Daucus carota* and *Xanthophyllomyces dendrorhous* as well as specific carotenoid genes under control of a Cup promoter or a Met promoter.

Colonies selected for carotenoid production were picked with a sterile toothpick and streaked sequentially onto selective plates corresponding to the four repressed and/or induced conditions (-Ura/-Trp (both promoters on), -Ura/-Trp/-Met (Cup promoter off, Met promoter on), -Ura/-Trp/+200  $\mu$ M  $\text{Cu}_2\text{SO}_4$  (Cup promoter on, Met Promotor off), -Ura/-Trp/-Met/+200  $\mu$ M  $\text{Cu}_2\text{SO}_4$  (both promoters on)). Results are shown in Figure 27. Replicas on media with one promoter induced and the other expressed showed some color development while the replicas on double inductive medium showed the brightest colors in a high proportion of replicas.

**Example 16**

**Preparation of cells expressing carotenoids and other antioxidants**

2 EVAC libraries were prepared as described in Example 10, pages 120-122.

EVAC library 1 was made using 5 plant libraries: *Aloe humilllis* (flowers), red chilli pepper (fruit), *Gerbera hummingbird* (flower), *Viola cornuta* (flowers) and *Spirea japonica* (leaves) as well as specific carotenoid genes. The plants were used in equal proportions and represented a total of 20% of the cassettes used in the EVAC preparation. The specific genes were also included in equal amounts and represented the remaining 80% of cassettes used in the EVAC preparation. This EVAC library was transformed into a haploid yeast strain of mating type  $\alpha$ , using the procedure described in example 11.

The specific carotenoid genes were:

ggps, psy, pds, zds, lcy-b, lcy-e, bhy, zep (*Gentiana sp.*), idi, crtC, crtF (*Rhodobacter capsulatus*), crtE, crtB, crtI, crtY, crtZ (*Erwinia uredovora*), zds (*Nostoc anabaena*), pds (*Synechococcus PCC7942*), crtE, crtB, crtI, crtY, crtZ (*Erwinia herbicola*), crtM, crtN (*Staphylococcus aureus*), crtI, crtYb (*Xanthophyllomyces dendrorhous*), ccs, crtL (*Capsicum annuum*), crtL, bchy (*Nicotiana tabacum*), lcy-b, lcy-e (*Prochlorococcus sp.*), idi (*Saccharomyces cerevisiae*), crtI, crtYe, crtYf, crtEb (*Corynebacterium sp.*), psy-1 (*Lycopersicon esculentum*), al1 (*Neurospora crassa*)

EVAC library 2 was made using 10 plant cDNA libraries, 1 moss library (*Pellia endiviaefolia*), 1 red algae cDNA library (*Polysiphonia fibrillosa*) and one mushroom (*Cantharellus cibarius*). The 10 plants used were *Viburnum fragrans* (flower), carrot (root), *Aloe humilllis* (leaves), *Lithops salicola* (leaves), cherry tomato (fruit), red chilli (fruit), coriander (leaves), *Gerbera hummingbird* (flower), *Forsythia intermedia* (leaves & shoots) and papaya fruit. All cDNA libraries were used in equal amounts. This EVAC library was transformed into a yeast strain of mating type a using the procedure described in example 11.

The yeast library containing EVAC preparation 1 was screened for oxidative stress resistance using the following anti-oxidant screen:

- a. The screening population was grown and the heterologous genes were induced/de-repressed by re-suspending the cells in selective medium lacking methionine and with 200  $\mu$ M  $\text{Cu}_2\text{SO}_4$ . The cells were grown under induction conditions for 24 hours prior to screening.
- b. The screening population was divided in 10 portions.

- 5                   c. Each sub population was exposed to 1 out of a range of 10 concentrations of Methylene blue. (0,1mM MB & 2 h. irradiation with 200W white fluorescence light kills 100% of the host). Immediately after exposure to Methylene blue, the cells were irradiated with a 200 W lamp for 2 hours. During the procedure it was ensured that the temperature remained constant at 37°C. The yeast host subjected to methylene blue and light, the cell population exposed just to light and the cell population exposed to methylene blue but not light were used as controls throughout the procedure.
- 10                   d. After exposure to methylene blue and light, the cell populations were washed to remove all traces of poison, re-suspended in selective media and stored at 0°C to avoid cell growth.
- e. Plating a dilution series and counting the number of colonies formed after 48 hours determined survival rates.
- 15                   f. The surviving cell population from the highest concentration of Methylene blue where cells statistically representing 1% of the original cell lines survived was taken forward.

20                   The cell culture subjected to the highest oxidative stress, where 1% of the cells survived (0.4 mM concentration of methylene blue) were mated with the yeast library containing EVAC library 2. Mating of the libraries was done using the following procedure:

- 25                   a. The selected library and the library containing EVAC library 2 were amplified so that enough copies of each clone exist to be able to mate with all cells of opposite mating type
- b. Cells from freshly grown overnight cultures of both populations were mixed and distributed in agar plates (the plates should allow growth of both haploid strains).
- 30                   c. Mating was allowed to proceed for at least 4 hours at 30°C and then the cells were washed off from plates.
- d. The mating mixture was incubated in a liquid selective medium that selects for the diploid genotype which contains all different types of EVACs

35

The newly formed diploid population was screened for oxidative stress resistance as described herein above. Again the cell culture subjected to the highest oxidative stress, where 1% of the cells survived (1.2 mM concentration of methylene blue) were selected. This selected cell population was sporulated and the newly formed daughter population was mated again to form a new diploid population. Sporulation was done using the following procedure:

- f. A portion of the selected diploid population was grown to an OD<sub>600</sub> of 2.5 to 3.0 ( $\sim 8 \times 10^7$  cells/ml) in selective medium.
- g. 1 ml of culture was transferred to a sterile, disposable 15 ml polypropylene tube and centrifuge 5 min at  $1200 \times g$ .
- h. The supernatant was poured off and the cells were washed in 5 ml sterile water.
- i. The cells were re-suspended in 1 ml of sporulation medium. (Sporulation medium, per litre: 10g potassium acetate (1%), 1g yeast extract, 0.5 g dextrose).
- j. Cells were shaken for 2 to 3 days at  $\geq 350$  rpm, 30°C, and the culture was examined microscopically for spore formation.

The disruption of spores was done the following way:

- a. The sporulation culture was pelleted and re-suspended in 5 ml water.
- b. Zymolyase-20T solution (ICN Immunobiologicals) and 2-mercaptoethanol were added and the spores were incubated overnight at 30°C with gentle shaking. (The Zymolyase kills any diploid cells that did not sporulate as well as haploid cells that have not mated).
- c. The supernatant is aspirated or poured off and the spores are re-suspended in 5 ml of water. Glass beads were added (Type I, Sigma) and the mixture was vortexed vigorously. The process is repeated until 90% of spores are disrupted.
- d. The spore populations are plated onto selection agar plates with CaCl<sub>2</sub> (25 mM CaCl<sub>2</sub>, 0.67% yeast nitrogen base w/o amino acids, 1xCSM (-TRP) (Q-biogen), 2% glucose and 2% or 2.5% agar) using top alginate. A suitable amount of selective top alginate was added so that 100000 cells are spread on 100-mm plates or 1000000 cells on 150-mm plates of selective top alginate: 5 ml (for 100-mm plates)

or 12 ml (for 150-mm plates). Top alginate is the same as the selection agar except that agar is substituted with Na-Alginate and  $\text{CaCl}_2$  is omitted. The use of selective media prevents the growth of cells lacking at least one EVAC.

- 5            e. The plates were quickly tilted or rotated from side to side as to distribute the agar solution evenly across the surface of the agar plate. The plates were left standing face up until top alginate has solidified.
- f. The plates were incubated for 2-6 days at 30°C until colonies appear.
- 10           g. The alginate from the plates was collected and transferred to a 50 ml tube (from two 100-mm plates or one 150-mm plate in one tube). 12 ml (per 100-mm plate) or 33 ml (150-mm plate) of 0.25 M Na-citrate (pH 6.2) were added and mixed thoroughly for 2.5 min.
- h. The cells were collected by centrifugation for 5 min at 2500 rpm. The supernatant was poured off and the cells were re-suspended in 50 ml
- 15           of  $\text{H}_2\text{O}$ .

The newly formed haploid population is a mixture of both mating types that will mate as soon as they are transferred from the water into rich media as described herein above.

- 20           The new diploid population was subjected to a third round of screening for oxidative stress resistance as described above. Again the cell culture subjected to the highest oxidative stress, where 1% of the cells survived (1.9 mM concentration of methylene blue) were selected.

- 25           After 3 rounds of screening for oxidative stress resistance, cells able to survive 20 times more oxidative stress than the untransformed host were obtained (see figure 28).

- 30           Also, after the first round of screen only yellow and orange colours were obtained (similar to Example 15, page 125) while after the second and third rounds yeasts producing pink and green colours were also obtained. See figure 29.

Yeast cells producing a number of different carotenoids were identified. Figure 30 shows the carotenoid content of 10 selected clones.